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INTERNATIONAL RAILWAY CONGRESS ASSOCIATION

13th SESSION (PARIS, 1937).

QUESTION II.

Use of welding :

1. to obtain extra-long rails ;

2. in manufacturing and repairing points and crossings.

a) **Results obtained by using extra-long rails. Methods used to ensure safe expansion of the rails and anchoring of the track.**

b) **Technical and financial results shown by welding points and crossings.**

REPORT

(Great Britain, Dominions and Colonies, America, China, Japan),

by George ELLSON,
Chief Engineer, Southern Railway (Gt. Britain).

A. — Welding together of rails.

NOTE. — *Of the 59 Administrations covered by this report, 10 have supplied particulars of welding carried out, 26 have not made use of welding in this connection and 23 have not replied to the questionnaire.*

History and extent of work.

The welding together of rails to form longer lengths is of comparatively recent introduction and does not appear to have been adopted to any extent prior to 1932. Since then a number of Administrations have made use of welding in one form or another, for the elimination of rail joints, notably the South African Railways, on whose system 121 miles of track are laid with welded rails; their lengths, however, do not exceed 84 ft.

Two railways in the U. S. A. have made considerable progress in the welding of rails into long continuous lengths; the Delaware & Hudson Railroad have over six miles of welded track, with continuous lengths of from 273 ft. to 6 900 ft., while the Bessemer and Lake Erie Railroad have a continuously welded length of one mile.

Other Administrations concerned are

the London Passenger Transport Board (Great Britain), whose two miles of welded track include a continuous length of 1 650 ft. laid in a « tube » tunnel, and the London and North Eastern Railway (Great Britain) with a continuous length of 1 260 ft.

In addition to these, the practice has also been adopted by a number of other railways in Great Britain, Japan and the U. S. A., where the work has been confined to experimental sections.

Location of welded track and traffic conditions.

Long welded rails exist in electrified and non-electrified track, and although most Administrations have confined their experimental lengths to straight track or curves of large radius, no such restriction is imposed in the U. S. A., where curves of 11 1/2 chains radius have been laid with continuously welded rails; while on the South African Railways welded rails 72 ft. long have been successfully laid in 2-ft. gauge track on curves as sharp as 168 ft. radius.

The density of traffic carried varies considerably, the heaviest being 445 electric trains per 24 hours passing over the London Passenger Transport Board's welded track, at a maximum speed of 40 m. p. h., and 100 electric trains per 24 hours passing at a maximum speed of 65 m. p. h. over a short length of welded track on the Southern Railway (Great Britain).

The heaviest axle loads carried by welded rail joints are 35 and 34 (English) tons on the Delaware & Hudson Railroad and Bessemer and Lake Erie Railroad respectively, who use flat-bottomed rails weighing 130 and 131 lb. per yard; in Great Britain axle loads of up to 22 1/2 tons are carried by welded joints with bull-headed rails weighing 95 lb. per yard.

Methods of welding.

Thermit process.

Up to the present the thermit process has been employed by most Administrations, having until recently been the method most suited to welding on the site.

Flash-butt or resistance welding.

The flash-butt or resistance welding process is preferred by those administrations who have adopted it, including the Japanese Government, Delaware & Hudson, and Central Argentine Railways. It is understood that on the Delaware & Hudson Railroad portable equipment is now available by which rails can be resistance-welded at site instead of in shops as was previously necessary.

Both the above processes are well known and need not therefore be described in this report.

Fishplate fillet welding.

The joining of rails by welding fishplates and sole plates on to the rails is the standard practice on the South African Railways, who have welded over 21 000 joints by this method (fig. 1).

Various types of fishplate fillet welds have also been tried by the Japanese

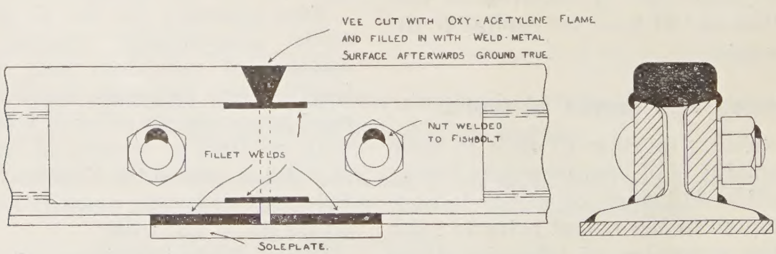

Fig. 1. — Welded rail joint. — South African Railways and Harbours.

Government Railways, but this Administration reports that these, together with thermit welds, have not given such satisfactory results as resistance welds.

Heat treatment.

The London Passenger Transport Board, the Japanese Gỏvernment Railways and the Delaware & Hudson Railroad make a practice of heating the rails after welding, this being carried out by means of a portable oil-burning furnace, gas flame or electric heating; other administrations have not yet adopted the post-heating of the rail as a necessary operation.

Personnel.

So far the thermit welding on the railways in Great Britain has been carried out by contract, the Railway Companies providing the necessary unskilled labour.

Welding by the same process is carried out by the Companies' own staff in the case of the Bessemer and Lake Erie and Delaware & Hudson Railroads (fig. 2) this work being supervised by Contractors in the case of the first-named Administration.

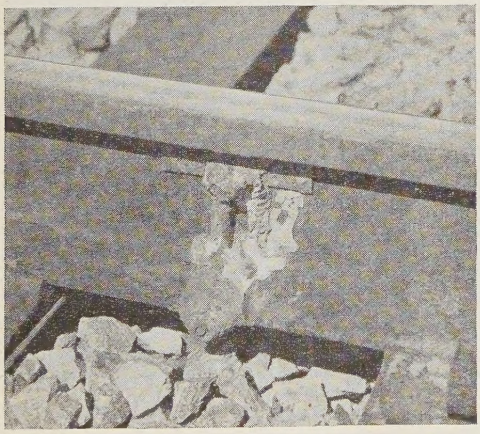

Fig. 2. — Close-up view of a thermit-pressure weld. — Delaware & Hudson Railroad.

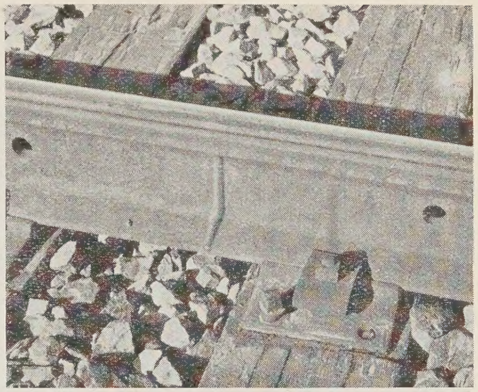

Fig. 3. — Resistance weld. Delaware & Hudson Railroad.

The resistance welding of rail joints on the Delaware & Hudson Railroad (fig. 3) is carried out by contract, and on the Central Argentine Railway by the Company's own staff.

On the South African and Japanese Government Railways, all welding is carried out by the Companies' own staff.

Handling and conveying the welded rails.

Since the rails are in most cases welded in situ, this question does not frequently arise, but an interesting example of the conveyance of long continuous lengths is given by the Delaware & Hudson Railroad. In this case, 39-ft. rails are welded into lengths of from 780 ft. to 1 482 ft., and the long rails are conveyed on flat trucks to the site (fig. 4) and unloaded by the use of a small crane and a gang of men with bars (fig. 5).

Testing and inspection of welded rail joints.

Specimen welds are tested in the shops by most administrations, the tup and bending tests being the most usual;

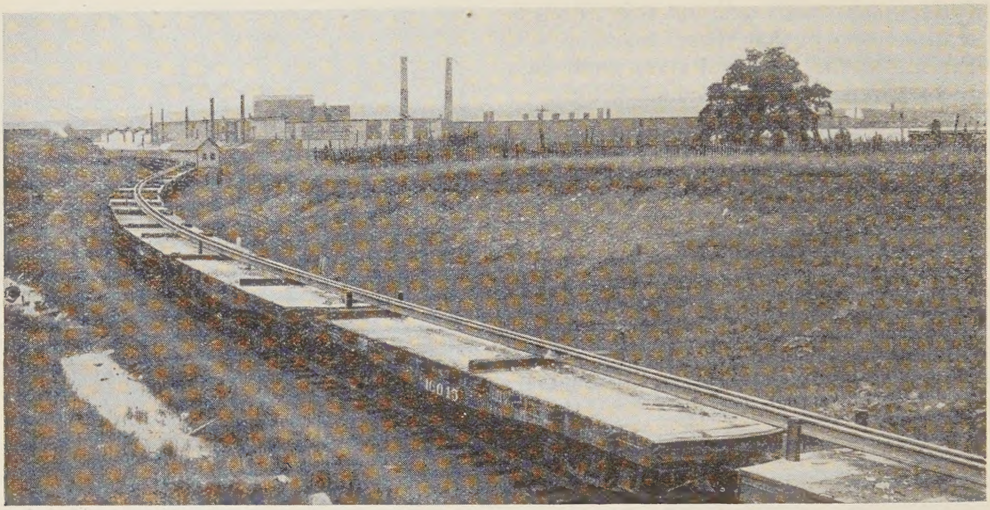

Fig. 4. — Conveying lengths of we ded rails to site (around 13° curves). Delaware & Hudson Railroad.

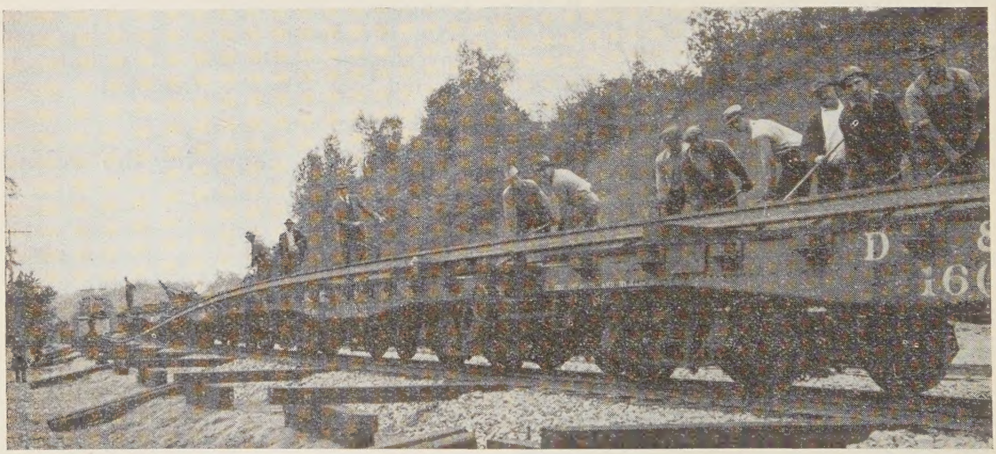

Fig. 5. — Unloading long welded rails at site.

tensile and electric conductivity tests, and examinations of texture are also applied in some cases.

In the track, the welded joints are not as a general rule subjected to any special test other than systematic visual inspection, but the extensive use of the Sperry detector in the U. S. A. affords an additional test of the soundness of the welds. Brinell hardness tests on the site are carried out by some administrations, and the Berry strain gauge is used on the Bessemer and Lake Erie Railroad.

Defects.

Slight hollowing of the surface at the welds has been noticed in some instances.

Fractures of welded rails at the welds are comparatively rare. The South African Railways report 107 fractures in 21 170 welds; of these 67 may be due to the fact that rails, being badly crippled at the ends, were cold-straightened before welding.

The only other cases of welded rail joints fractured in the track have been reported by the Delaware & Hudson Railroad, numbering 8 in a total of over 1 400 welds.

Expansion and track fittings.

No special rules have been adopted governing the expansion gap to be allowed between the long welded rails, and the general conclusion is that, in the respective conditions mentioned, little or no addition need be made to the normal expansion gap for rails of ordinary length.

The longest continuously welded length of bull-head track recorded is the 1 650 ft. on one of the London Passenger Transport Board's « Tube » lines, where the range of temperature is low, being only about 20° F. In this case the sleepers are of Jarrah, laid on concrete, and the standard gaps for 60-ft. rails, with standard fishplated joints, are provided at the ends of the welded length.

In U. S. A. the long lengths already referred to are subject to a much greater range of temperature (about 125° F.) but it is found that the standard track equipment provides sufficient resistance to expansion and creep, and only the standard gaps for 39-ft. rails are provided at the ends of the welded length, with standard fishplated joints.

The greater lateral and vertical stiffness of flat-bottomed rails of heavy section by comparison with bull-head rails is a factor which may render the former type more suited to welding into long continuous lengths, providing as it does a higher degree of resistance to distortion when the rails are in compression.

The Japanese Government Railways make a practice of increasing the normal gap at 10° C. from 6 to 8 mm. for two 12-metre rails welded together; in this case the ballast is sieved gravel, and the rails are dog-spiked to the sleepers.

The spacing of sleepers is not as a rule subject to any modification on the welded lengths, the standard spacing varying from 1 600 to a mile on the London Passenger Transport Board's Tube lines to 2 970 to a mile on the Bessemer and Lake Erie Railroad.

In very few cases have any special appliances been used for adjusting the long welded rails.

Costs.

The relative costs of thermit-welded and fishplated joints are somewhat variable, owing to the conditions under which the work was carried out and the difference in the costs of the various types of fishplates.

Thus in Great Britain, where the welding has so far been carried out on an experimental scale and where the cost of fishplates is comparatively low, the cost of a thermit-welded joint is from 4 to 13 times that of a fishplated joint without bonds, or from 1.3 to 4.5 times that of a bonded fishplated joint.

In the U. S. A., however, where thermit welding has been carried out on a large scale and where the fishplates are more costly, the cost of a thermit- welded joint is from 1 1/2 to 3 times the cost of a fishplated joint without bonds.

The only figures regarding flash-butt welding are supplied by the Delaware & Hudson Railroad, who record that the cost of a joint welded by this method is

from 1 to 2 1/2 times that of a fishplated joint.

The Japanese Government Railways give the cost of an arc-welded joint as 0.6 to 0.9 of that of a normal fishplated joint, depending on the method of bonding, while on the South African Railways the cost of the two types of joint is about the same.

Regarding the relative value of recovered long welded rails and rails of ordinary length as serviceable material for re-use in secondary lines or sidings, this would appear to depend on the work required to be done on the rails before they can be used again.

In some cases it is proposed to remove the long rails bodily from the track, subsequently cutting them into shorter lengths as required; in others it is proposed to cut them before removal.

Where the cutting of the rails is involved, the cost of drilling and providing second-hand fishplates, or the additional cost of re-welding, has to be taken into consideration, and the estimates of the second-hand value of welded rails vary between 60 and 100 % of the value of the same weight of unwelded rails. In this connection, however, the Delaware & Hudson Railroad anticipate that they will, by the elimination of the joint, be able to secure the full life of the rail in the main-lines.

With regard to the scrap value of the rails, it is generally agreed that this will not be affected by welding.

Advantages obtained by welding rail joints.

These may be summarised as under :

1) Pounding of joints eliminated, giving a smoother riding track and reduction of noise, thus increasing the comfort of passengers.

2) Saving in labour maintaining surface and alignment at joints.

3) Saving in maintenance of rolling stock.

4) Improved conductivity for traction return current and track circuits, and saving in cost of bonding.

An important advantage, which is apparent to a greater extent in the U. S. A. than elsewhere, is due to the fact that on the lines in that country, many rails have to be prematurely removed owing to local wear on the head of the rail due to battered joints. The elimination of joints therefore results in a longer rail life with a consequent saving in labour and material.

Future proposals.

While certain of the administrations concerned are awaiting further experience with their experimental welded lengths, the majority intend to continue the practice; the Delaware & Hudson Railroad in particular had a programme involving the welding of 9 miles of track in 1936, and from 20 to 25 miles in 1937.

* * *

B. — Application of welding to the construction of permanent way materials.

NOTE. — *Of the 59 Administrations covered by this report, 6 have supplied particulars of welding carried out, 30 have not made use of welding in this connection, and 23 have not replied to the questionnaire.*

History and extent of work.

The application of welding to the construction of permanent-way materials is somewhat limited, being confined mainly to the fabrication of steel sleepers, although welding has also been used in the construction of a small number of switches and crossings.

Welded steel sleepers were first constructed in 1926 by the Delaware & Hudson Railroad (U. S. A.) from scrap rails, fish-plates and sole plates; over 118 000 of these are in use in sidings.

In 1930 a type of pressed steel sleeper

with steel chairs welded on was adopted in Great Britain, the London and North Eastern and Southern Railways having about 6 000 and 38 000 of these in use respectively.

The use of welding in the construction of switches and crossings appears to date from 1930, since when the Bombay, Baroda and Central India Railway has had 28 units constructed in this way; other administrations who have experimented with this method of construction are the South African and Japanese Government Railways.

In view of the different nature of the two classes of unit, it will be convenient to deal with (1) steel sleepers and (2) switches and crossings under separate headings.

(1) *Steel sleepers.*

The type of steel sleeper constructed by the Delaware & Hudson Railroad

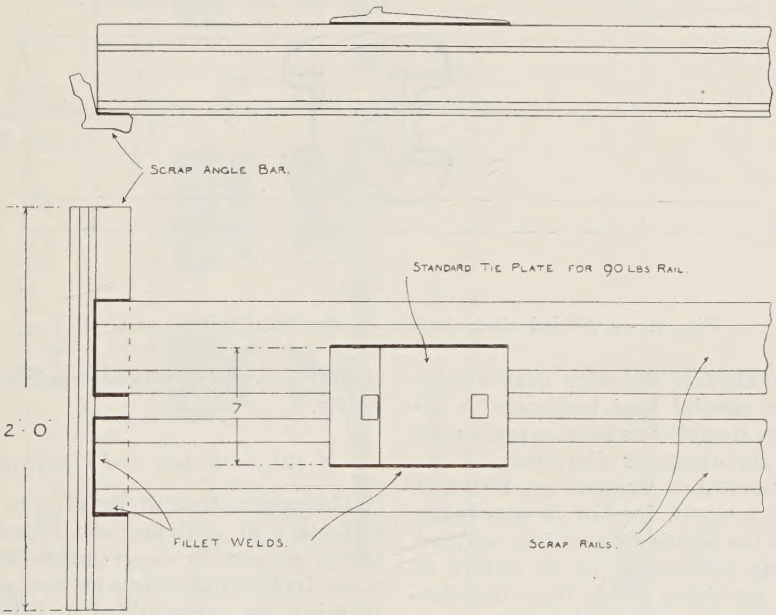

Fig. 6. — 8-foot welded steel tie. — Delaware & Hudson Railroad.

(fig. 6) consists of two lengths of scrap rail about 8 feet long spaced at 7-in. centres, heads uppermost. These are joined by welding scrap angle fishplates across the ends, and suitable sole plates are welded to the top of the sleepers so formed, the welds being centrally disposed on the heads of the two rails. Although confined to yard tracks where speeds do not exceed 25 m.p.h., these sleepers are capable of carrying axle loads of 35 (English) tons, and no failures have been reported.

The welded steel sleeper in use on the London and North Eastern and Southern Railways (fig. 7), is manufactured by contractors, and consists of an inverted trough, the top surface of which is pressed to receive pressed steel chairs, which are fillet-welded in position.

These sleepers are used in main lines, and are subjected to traffic at speeds of up to 65 m.p.h.; no defects have occurred and the sleepers have proved satisfactory.

In both cases the welding is carried

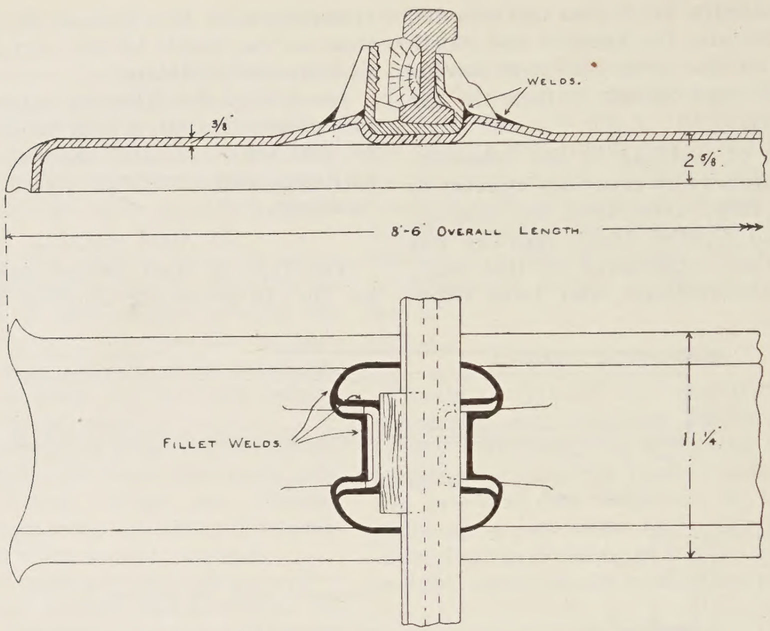

Fig. 7. — Welded steel sleeper. — Southern Railway (Gt. Bn.).

out by the electric arc with coated electrodes; no special heat treatment is given, and no trouble has been experienced owing to shrinkage or distortion.

The pressed-steel sleepers are tested at the works, a tensile load of 15 tons being applied to the welded chair jaw without causing any permanent set or failure of the weld; specimen welds from the electrodes used are also tested for structure and chemical analysis.

The cost of this type of sleeper is from 3 to 9 % more than that of an ordinary creosoted and chaired wooden sleeper; no comparative figures are available in the case of the type of sleeper in use on the Delaware & Hudson Railroad.

In general the results obtained from these sleepers have been satisfactory, and in two out of three cases it is proposed to continue their use, subject (in common to all types of steel sleepers) to their restriction to lines which are not electrified, and also having regard to the difficulties which may arise where track circuiting exists.

(2) *Switches and crossings.*

The application of welding to the manufacture of switches and crossings has barely passed the experimental stage, but some interesting examples are given, indicating the possibilities of this method of construction.

This work was first tried in 1930, by the Bombay, Baroda and Central India Railway, for whom an English firm has supplied 15 switches and 13 crossings, in the construction of which welding has been used in several ways (fig. 8). These units carry up to 100 electric trains per day at speeds of up to 45 m.p.h., with axle loads of over 21 tons.

The Japanese Government Railways have 12 crossings (fig. 9) and a number of switches (figs. 10 and 11) constructed by welding (also by contractors), while

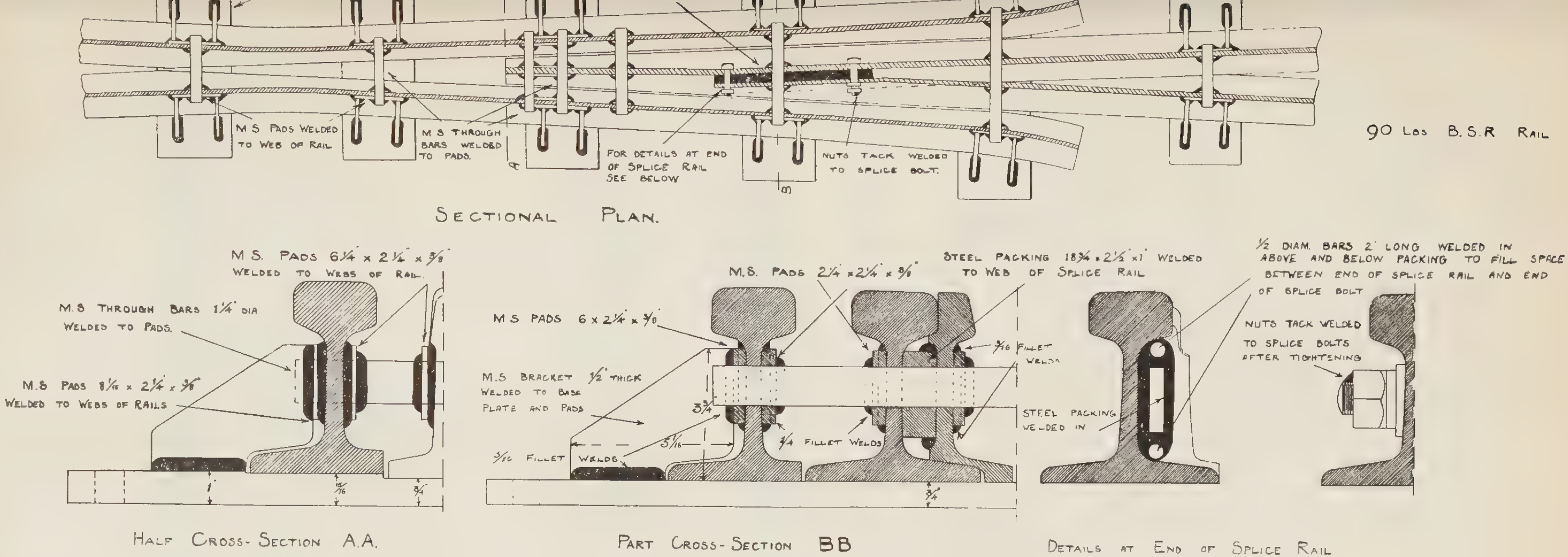

Fig. 8. — 1 in 12 crossing fabricated by welding. — Bombay, Baroda & Central India Railway.

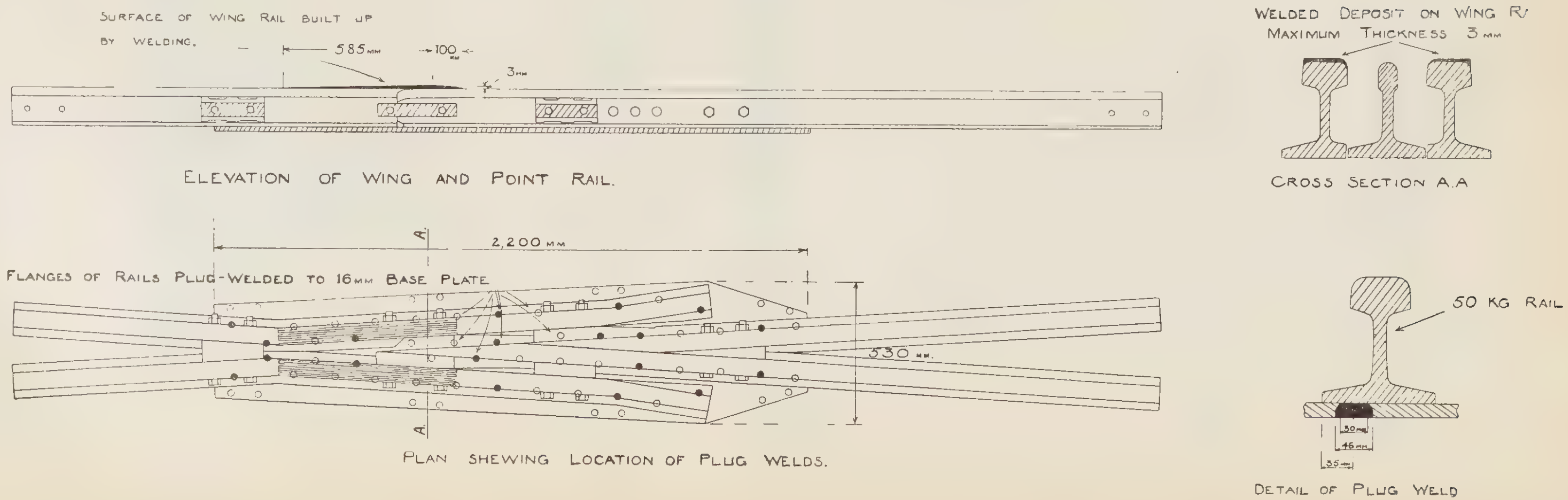

Fig. 9. — 1 in 8 crossing fabricated by welding. — Japanese Government Railways.

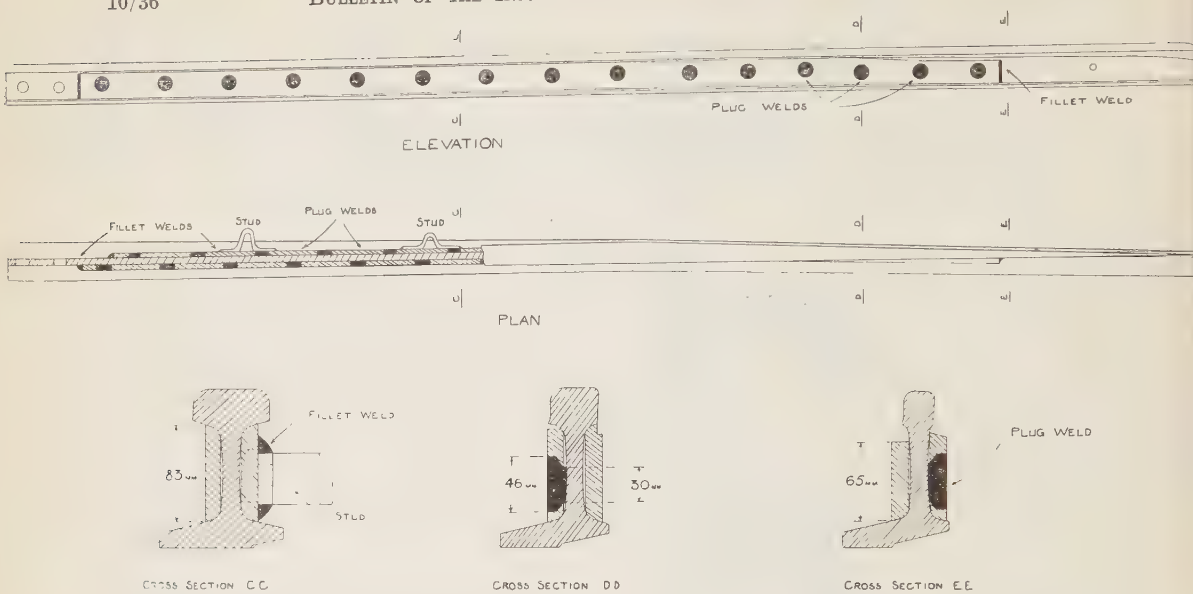

Fig. 10. — Switch with plug-welded reinforcing plates. — Japanese Government Railways.

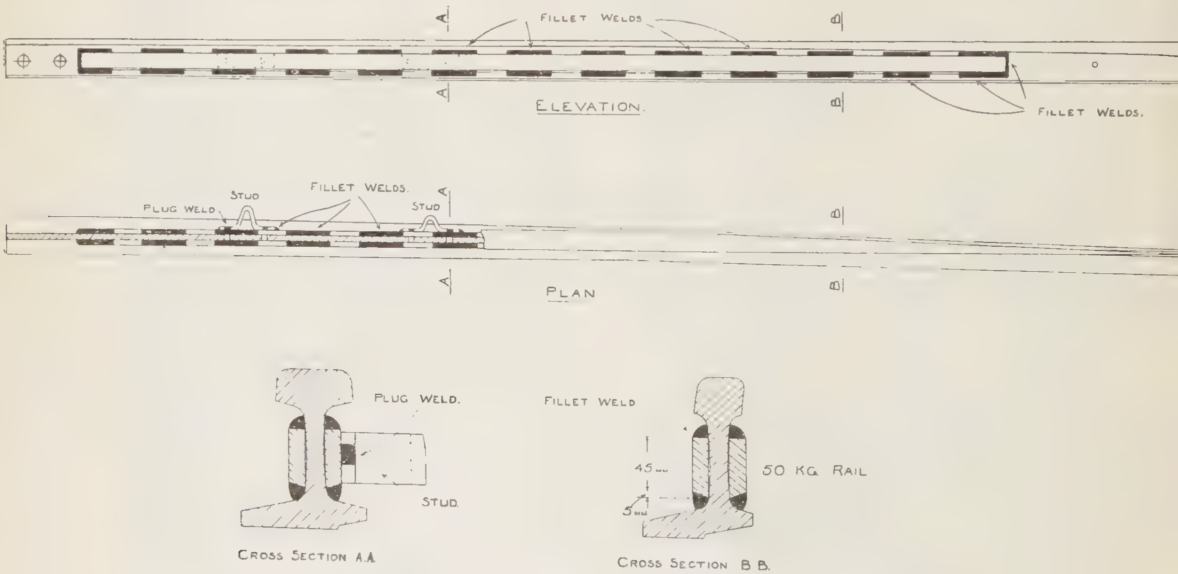

Fig. 11. — Switch with fillet-welded reinforcing plates. — Japanese Government Railways.

the South African Railways have fabricated about 20 welded crossings, the work in this case being done by the Company's own welders. These are mainly wide-angle diamond crossings at the intersection of railway and tram tracks

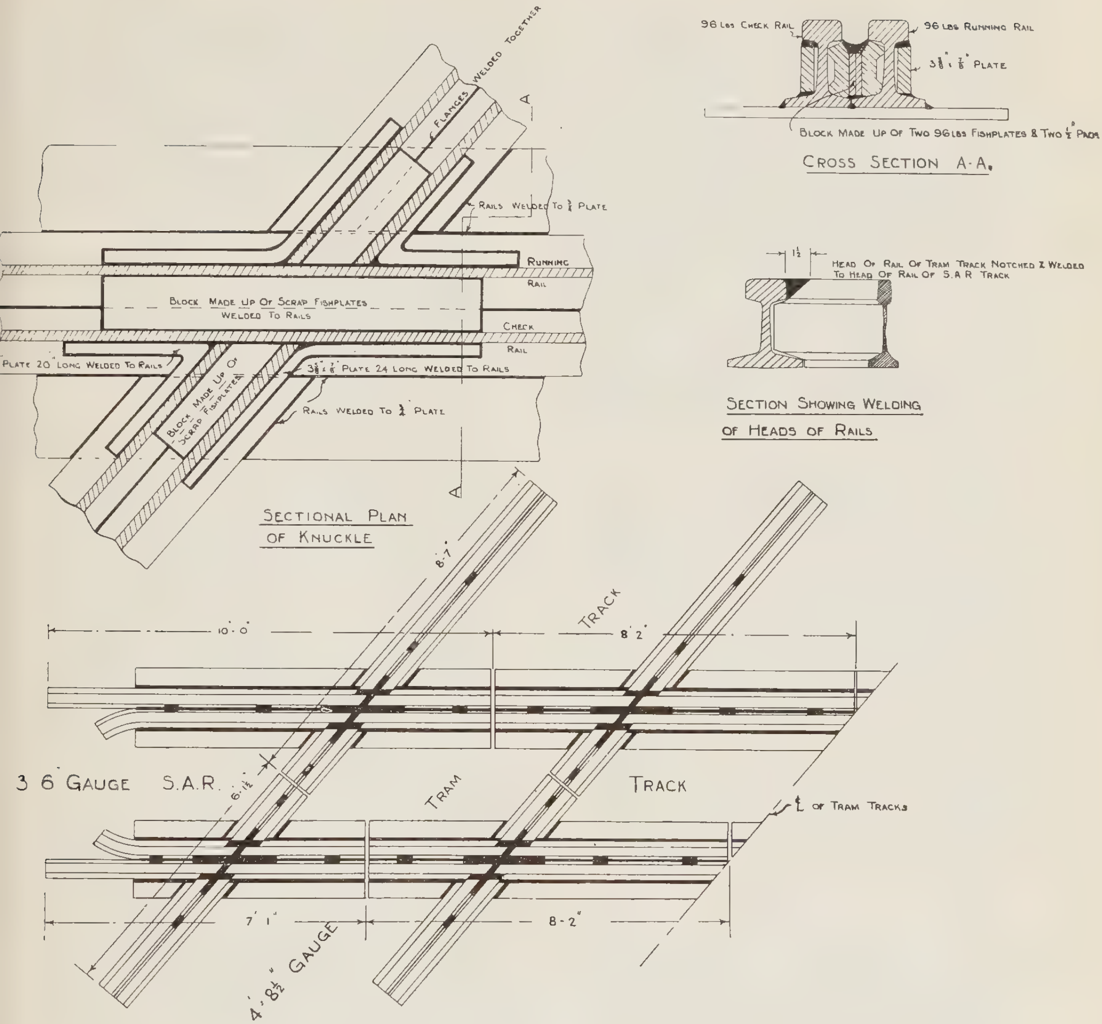

Fig. 12. — Diamond crossing fabricated by welding. — South African Railways and Harbours.

(fig. 12); the speeds of both classes of traffic are low (6 m.p.h. for trains and 8 m.p.h. for trams) but the amount of traffic is comparatively high, the most heavily loaded crossing carrying 48 trains and 304 trams per day.

A certain amount of distortion has been experienced in two cases; in the case of the Bombay, Baroda and Central India Railway's welded crossings, this has been overcome by heating the work and maintaining it at that temperature during the whole of the welding, also by first welding pads of mild steel on to the webs of the rails, while in the case of the crossings made for the Japanese Government Railways, the distorted parts are heated and straightened.

The results obtained from these welded units are somewhat variable. The Bombay, Baroda and Central India Railway report defects in the case of 10 %, while the Japanese Government Railways have experienced trouble in 58 % of their welded units through cracks developing either in the plug weld joining the rail to the base-plate or in the flange of the rail. The South African Railways, on the other hand, have had no defects since the first experiments, and report that the welded crossings in question give better service than those constructed with bolts in the ordinary way, besides being only about one fifth of the cost.

The cost of the welded units in use on the Bombay, Baroda and Central India and Japanese Government Railways are, however, from 22 % to 56 % higher than corresponding types constructed in the usual way.

Although in the last two cases the results have not so far been very successful, the administrations concerned are considering continuing trials with welded switches and crossings; and the South African Railways, in view of their satisfactory experience, propose to continue to adopt this method of construction.

* * *

C. — Application of welding to the reconditioning of permanent way materials.

NOTE. — *Of the 59 Administrations covered by this report, 24 have made use of welding in this connection, 12 have not done so, and 23 have not replied to the questionnaire.*

History and extent of work.

Unlike the applications of welding dealt with in parts (A) and (B) of this report, the reconditioning of permanent way materials by welding has been widely adopted, and in most cases may be said to have passed the experimental stage and, in one form or another, to have become standard practice.

It will be convenient to classify the units which have been reconditioned under the following headings :

a) Rails in plain line,
b) Switches,
c) Frogs and crossings,
d) Steel sleepers and other units,

and to review the development of each type of reconditioning separately.

(a) *Rails in plain line.*

The building up of battered rail ends was first carried out by the Pennsylvania Railroad (U. S. A.) in 1918, since when about 2 400 miles of track have been dealt with on this line alone. Other administrations who have adopted this practice are the Delaware & Hudson Railroad (U. S. A.) (about 115 500 rail-joints), the Baltimore and Ohio Railroad (U. S. A.) (about 25 000 rail joints) and the Long Island Railroad (U. S. A.) (about 60 miles), while the South African Railways have reconditioned about 10 000 rail joints.

The resurfacing of battered rail ends by welding appears so far to have been confined generally to the lines in the U. S. A. and South Africa; the only other administrations adopting this practice to any extent being the Japanese Government Railways, who have recently commenced this work and record 64 rails dealt with in this way.

(b) *Switches.*

The Pennsylvania Railroad carried out this class of work in 1918; its application in this case is somewhat limited, being generally confined to switches in yards only.

The Reading Railroad has, however, made extensive use of this process, some

11 000 switches having been built up by welding on this Company's lines; the Great Western Railway (Great Britain) and the Japanese Government Railways also record the reconditioning of 800 switches and stock rails, and 74 switches, respectively.

(c) *Frogs and crossings.*

NOTE. — *Although most of the American administrations have supplied separate particulars in respect of each type of unit, the word « crossing » is taken by the other administrations to refer to both types, and no differentiation is made in the replies to the questionnaire forwarded by the latter. It will therefore be convenient to consider both types of unit together, and the word « crossing » will hereafter be used in accordance with British practice to denote both frogs and diamond (or obtuse angle) crossings.*

Taking the whole of the administrations concerned into consideration, the building up of worn crossings may be regarded as the most widely favoured application of welding, in view of the fact that every one of the 24 administrations who have made use of welding in any form of reconditioning of permanent way material has applied this process to crossings, the number of such reconditionings carried out up to the present time amounting to roughly 55 500.

This class of work appears to have been first tried in 1924, since when the practice has developed extensively, particularly on the railways of Great Britain.

In the latter country the Southern Railway have carried out about 17 500 reconditionings, the London Midland and Scottish Railway about 14 000, the London and North Eastern Railway about 8 500 and the Great Western Railway about 6 100.

In South Africa, India, Burma, and the Sudan the welding of worn crossings is carried out by a number of administrations, the South African Railways in particular having dealt with about 3 600 crossings in this way.

In the U. S. A. the practice on the whole does not, so far, appear to have developed to the same extent as the reconditioning of rails in plain line; the Baltimore & Ohio and Delaware & Hudson Railroads, however, have carried out about 1 700 and 1 200 reconditionings of crossings respectively.

In South America, the Central Argentine and Buenos Ayres Pacific Railways have respectively dealt with about 1 100 and 900 crossings.

(d) *Steel sleepers and other units.*

No cases are recorded of the systematic repairing of damaged or defective steel sleepers.

So far as other units are concerned, the only case is reported by the Reading Railroad, who have reconditioned a number of angle fishplates by welding.

Conditions of wear to which the reconditioned materials are subjected.

The reports from the various administrations provide ample evidence that the reconditioned materials are capable of standing up to the heaviest conditions causing wear, such as high speeds, heavy axle loads and intensive traffic. In this connection it may be noted that suburban electric services give rise to particularly heavy wear, not only because of the frequency of the trains, but also because of the small driving wheels, considerable unsprung loads and rapid acceleration and braking.

It is under such conditions that reconditioning of crossings by welding has proved particularly successful, since before the extensive adoption of this practice, crossings required very frequent renewal by reason of purely local wear on the point and wing rails, whereas such

worn rails can be resurfaced by welding for a fraction of the cost of renewal.

Examples of heavy traffic over welded crossings are provided by the London Passenger Transport Board, on whose lines certain crossings carry about 445 trains in the 24 hours; the Southern Railway (Great Britain) about 250 trains per 24 hours; and the Great Southern Railway (Ireland), the Buenos Ayres Pacific and the Central Argentine Railways about 200 trains per 24 hours.

While the density of traffic passing over reconditioned permanent-way materials is considerably lower in the United States, the axle loads are very much heavier. The Pennsylvania Railroad records a maximum axle load of about 38 (English) tons, and in no case does the maximum axle load fall below about 30 tons on the railways of the U. S. A. who have supplied particulars regarding reconditioning by welding. Elsewhere the greatest axle load is recorded by the Great Western Railway (Gt. Britain) with 22 1/2 tons.

Speeds of up to 90 miles per hour are recorded by the various administrations, indicating that reconditioned materials are capable of standing up to the heavy hammering associated with high speeds.

Methods of reconditioning.

Electric arc welding is the method generally employed by the administrations who follow the practice of reconditioning, although resurfacing by oxy-acetylene welding is now being developed, and has been adopted to some extent in the U. S. A.

So far, however, in cases where both methods have been tried, arc welding has generally been found to be more satisfactory, although some administrations prefer gas welding under certain conditions. For example the Pennsylvania and Long Island Railroads use gas welding for building up worn switch tongues, and the Reading Railroad confines the use of arc welding to alloy steels, employing gas welding for ordinary steels.

Although the welding of high manganese steel rail is still in the experimental stage in most countries, in the U. S. A. the process of building up cast manganese steel crossings by arc welding is an established practice.

Preparatory work on rails.

With regard to the preparatory work on the unit to be reconditioned, it is a generally accepted principle that the rail surface should be thoroughly cleaned of rust and grease, and all defective metal removed, before the welding is commenced. The method usually adopted is to grind off the surface to be welded, and if any cracks are found, to grind out the metal affected, using a portable grinding wheel driven through a flexible shaft by an electric motor, which in the case of arc welding is worked off the generator set.

As in the case of the welding of rail-joints, the question of heat treatment before or after reconditioning appears to be controversial. Pre-heating to 200-300° C. by means of an electric heater is practised by three out of the four main railway groups in Great Britain. The London Passenger Transport Board require the crossings to be pre-heated to 240° C., and post-heated to 400° C.

On the Burma Railways, the rails are pre-heated to between 200 and 300° C., and afterwards cooled slowly in ashes (the welding in this case being done in the shops), while the Japanese Government Railways have also experimentally post-heated and annealed some rails and switches after welding, but this process has only been applied to such crossings as may have become deformed by gas welding.

In North and South America the Delaware & Hudson and the Pennsylvania Railroads apply pre-heating (the former by means of a gas torch), while the Bal-

timore & Ohio Railroad (in the case of reconditioned rail ends only) applies heat both before and after welding; on the Buenos Ayres Pacific Railway the work is pre-heated only in the winter. Elsewhere the process is not applied.

Two methods of testing the ground surface for hair cracks are in use in Great Britain. One is to oil the surface with kerosene, strike with a hammer and examine closely under an illuminated magnifying glass; while the other is to magnetize the surface by drawing a bar magnet along it, and float over it a suspension of iron-dust in methylated spirit, the iron-dust collecting at the cracks and rendering them easily visible.

With the oxy-acetylene process, the preparation of the rail is often confined to chipping away laminated metal and cleaning the surface with a wire brush, while the Baltimore & Ohio and Reading Railroads, who use both gas and arc welding, state that no preparatory work is done on the rails at all.

Preparatory work on track.

In addition to the various preliminary operations on the rails themselves, described above, it is a generally recognised principle that in order to derive the fullest benefit from the reconditioning process, the track as a whole in the neighbourhood of the part to be welded must receive careful attention, so as to ensure that the true surface restored by welding is not promptly destroyed as a result of movement caused by wear in other parts of the track or by insufficiently packed timbers.

This preparatory work on the track comprises, in the case of the building up of battered rail ends, the packing (and in some cases renewal) of the joint timbers, the reversal of fishplates or fitting of repair fishplates, the tightening of fish-bolts and aligning of the track. On the South African Railways distorted rail ends are bent up before being reconditioned.

In the case of the reconditioning of crossings the timbers are soundly packed, the cross level of the rails adjusted, any wear in the fittings taken up by the insertion of packings of suitable thickness under the worn parts, and all bolts tightened up.

In certain cases where the reconditioning work is carried out in shops, advantage is generally taken of this to strip the crossings and replace any worn or defective parts before the work is commenced; while on the Japanese Government Railways the crossings are fastened back to back before arc welding to prevent distortion, or the crossing rails are bent over a plate 12 mm. thick before oxy-acetylene welding.

Welding.

The actual processes of depositing weld metal by the electric arc or oxy-acetylene flame are well known and call for no detailed description in this report. Although in some cases the welding is only done in shops, the practice on most railways is to carry out the whole of the work in the track between trains, since the process is capable of being interrupted without detriment to the quality of the work. Welding is, however, generally suspended during periods of frost or very cold weather.

Finishing.

The production of a true finished surface is of considerable importance, since it is on this that the life of the reconditioned unit to a large extent depends. The normal practice adopted in conjunction with arc welding is to grind off the surface with a portable grinder such as has already been described, gauging the work by means of a straight edge and template. On the Southern Railway (Great Britain) the use of this equipment is supplemented by a careful study of the marks of the wheels of vehicles passing over the partly ground surface, and each

crossing finished off to suit the particular form of wear to which it is subjected. In the case of units built up by gas welding, however, the required surface is obtained by the use of a hand hammer and flatter on the deposit while still in a plastic condition.

Tests.

Apart from occasional tests of welds in cases of defects or experimental work, laboratory or workshop tests of the welding are not generally applied; where such tests are carried out they usually take the form of impact and hardness tests, and macro- and micro-photographic examination of the texture of the weld metal and of the effect of heat on the parent metal, supplemented in some cases by magnetic tests on polished sections, as already described.

As will be seen from the particulars of Brinell hardness submitted by the various administrations, the hardness of the welded deposit is in most cases greater than that of the parent metal, the usual increase in the Brinell number being from 30 to 60, although a few cases of much greater increases are recorded, and also instances where the deposit is slightly softer than the parent metal.

The only cases recorded where special tests of the soundness of the welding on site are the magnetic tests applied by the London and North Eastern Railway, the Southern Railway and the London Passenger Transport Board, by which any hair cracks or other imperfections in the finished work are revealed, and the hardness tests carried out on the site by the Baltimore & Ohio Railroad.

The reconditioned units are in many cases specially examined by a welding supervisor or technical assistant as they are completed, and, in addition to the normal regular track inspection by the permanent-way ganger, are in some instances specially inspected from time to time by the welding staff.

Defects.

Where figures have been supplied giving the percentage of fractures and cracks which have occurred in reconditioned units (excluding defects in experimental work), these are seen to be very low, indicating that on the whole the present materials, technique and method of supervision ensure a high degree of safety.

Costs.

An analysis of the comparison between the costs of reconditioning and of renewing the various types of units reveals fairly consistent results, as follows :

(1) *Reconditioning of rails.*

Considering only those administrations who have carried out a comparatively large amount of this work, the cost of reconditioning is from 3.5 to 5 % of the cost of renewing the rails.

(2) *Reconditioning of switches.*

On the same basis the cost of this work varies between 7.5 and 12.5 % of the cost of renewing the switches.

(3) *Reconditioning of crossings.*

In most cases the cost of reconditioning crossings lies between 10 and 25 % of the cost of renewal, although figures ranging from 5 % to 40 % are obtained from the costs quoted. Taking an average for the 18 administrations who have submitted particulars both of the number of crossings welded and the comparative costs (taking into consideration the number of crossings welded in each case), the average cost of reconditioning is found to be 14.5 % of the average cost of renewal.

(4) *Reconditioning of steel sleepers and other units.*

No particulars regarding costs have been supplied under this heading.

Life of reconditioned units.

A factor which must be taken into

consideration when reviewing the economy which is effected by welding is the amount by which the original life of the unit is prolonged by each reconditioning, and the number of successive reconditionings carried out.

It will be seen from reference to the particulars supplied by the various administrations that there is a considerable variation in the estimates of the percentage extension of the original life by each reconditioning, which range from 20 to 300 %.

An average for the 10 administrations who have supplied these particulars (taking into account the number of units reconditioned in each case, as before) is found to be 59 % for all types of unit, 60 % for reconditioned rails and switches, and 56 % for reconditioned crossings.

With regard to the number of successive reconditionings which may be carried out on a rail or crossing, this is limited in many cases by the life of that part of the unit not subjected to the local wear which gives rise to the necessity for reconditioning, apart from any consideration of the cumulative effect of repeated welding on the structure of the parent metal. The reports indicate that four times may be regarded as the usual maximum, although 10 successive reconditionings have been carried out on the Reading Railroad (U. S. A.).

Personnel.

In nearly every case the welding is carried out by the administrations' own employees, although in three cases where the number of units welded has not reached a large figure, the work has so far only been done by contract.

The Delaware & Hudson Railroad, however, carry out about 90 % of their reconditioning by contract; while a number of other U. S. A. administrations also do a portion of the work in this way. Thus on the Reading Railroad, gas and arc welding are carried out by the Company's own staff and by contractors respectively; and on the Pennsylvania and Long Island Railroads some cast manganese steel crossings have been reconditioned by contract, the rest of the work being done by the administrations' employees.

Training.

In some cases the reconditioning is carried out by welders already experienced in structural work, but the practice most generally adopted is to train men specially for this type of work. This training is sometimes carried out by the manufacturers of the electrodes or welding plant; more usually the man starts in the track as a welder's mate, is trained (by the railway company) for a short time in the shops, and is then given instruction on the track under the supervision of a qualified welder. The total period of training varies considerably, from a few weeks to about six months.

CONCLUSIONS.

In almost every case the administrations report that reconditioned units have proved as satisfactory as new ones; it is in fact claimed by the Japanese Government Railways that reconditioned materials give better results. In the three cases where the results are not regarded as successful, the work does not appear to have passed the experimental stage; in one case the cost of the work was high, and in another rapid wear was experienced in the welded deposit.

Apart from the last two cases all the administrations concerned propose to continue with this work, thus affording an adequate proof of the general success of this application of welding under the various conditions met with throughout the countries covered by this report.

(See hereafter Summary of individual replies of Railway Administrations to the Questionnaire.

Group 1. — **Weld**

—	GREAT BRITAIN.			
	Great Western.	London & North Eastern.	Southern.	London Passeng Transport Boar
Part 1. — Statistical information.				
QUESTION 1. — *Please give the following particulars so far as your Company is concerned :*				
(a) *Year when welding of rails was started.*	1935	1935	1932	1934
(b) *Approximate total length* of track *laid with welded rails,* in miles :				
(1) *Non-electrified* .	0.11	0.44	0.05	Nil.
(2) *Electrified.* . .	Nil.	Nil.	0.23	2
(c) *If any are laid in curved track, please state minimum radius of curve.*	Straight track only.	660 ft.	Straight track only.	Straight track on
(d) *Number of trains per 24 hours on the section of track laid with welded rails which carries the heaviest traffic.*	...	16	100	445
(e) *Maximum axle load* .	22 1/2 tons.	22 tons.	21 tons.	12 tons.
(f) *Maximum speed,* m.p.h.	About 30	40	65	40
(g) *Weight of rails when new,* lb. per yard. .	95	95	95	95
(h) *Length of rails before welding,* feet.	60	45 and 60	45 and 60	90 and 59
(i) *Length of long rails when welded,* feet.	120	1 260 and 180 respectively.	90 and 120 respectively.	In open track 2 In tunnels 1 65

ether of rails.

AFRICA.	JAPAN.	UNITED STATES OF AMERICA.			SOUTH AMERICA
uth African.	Japanese Government.	Bessemer & Lake Erie.	Delaware & Hudson.	Reading Co.	Central Argentine.
1933	1934	1935	1933	Only a few rails in station platforms and road crossings have been welded.	1934
ox.: 4.375 miles 0-lb. track; 94 mi- of 60-lb track; 23 s of 45-lb. track.	Nil.	1	Albany, 1.14 miles; Mechanicville, 0.95 mile; Schenectady, 2.23 miles; Windsor, 1.83 miles.	...	Laid in short isolated lengths on electrified and non-electrified tracks.
Nil.	787' 6"	Nil.	Nil.	...	...
ft. radius on . gauge 45-lb. ck.	Straight track only	1 000 ft.	764 ft.	...	Straight track only
No statistics available.	22	1 passenger train and 10 freight.	Av. annual tonnage: 12 260 322 tons.	...	About 85.
esent Max. . C. permissible . 13.9 18 tons . 12.11 14 » . 7.1 1/2 10 »	14.76 tons.	33.84 (Engl.) tons.	34.93 (English) tons.	. .	18 tons.
b. — 55 m.p.h. b. — 35 m.p.h. b. — 25 m.p.h.	50	Passenger trains, 45 m.p.h. Freight trains, 35 m.p.h.	45	...	54
), 60 and 45.	100.8	131	130 and 131.	...	85
21, 24, 30, 33	39' 4 1/2"	39	39	...	40
84, 72, 60, 66 respectively.	78' 9"	Continuous welding for entire length of one mile.	273 to 6 900	...	79' 10 7/16".

—	GREAT BRITAIN.			
	Great Western.	London & North Eastern.	Southern.	London Passenger Transport Board.
Part 2. — Technical particulars.				
QUESTION 2. — (a) *What methods of welding rails together have you tried?*	Thermit (Shim) process only.	Thermit (Shim) process only. (One experiment only.)	Thermit (Shim) process only.	Thermit process on
(b) *Which have you found the most satisfactory.*	...	...	...	...
QUESTION 3. — (a) *Do you subject the rail to a heat treatment after the welding has been completed.*	No, only slow cooling.	No.	No.	Yes.
(b) *If so, what is done?*	...	...	...	Post-heat to 800 — 850° C.
QUESTION 4. — *Do you weld the rails :* (a) *on or near the site?*	Yes.	Yes.	Yes.	Yes.
(b) *in shops?.*	No.	No.	No.	No.
QUESTION 5. — *In the latter case, what is the maximum length that you can weld in the shops before conveying the welded rails to the site?*	...	...	...	...

…AFRICA.	JAPAN.	UNITED STATES OF AMERICA.			SOUTH AMERICA.
…uth African.	Japanese Government.	Bessemer & Lake Erie.	Delaware & Hudson.	Reading Co.	Central Argentine.
…Fishplates and … plates fillet …ded by oxyace…ene welding. … Ditto electric welding.	(1) Fishplates and sole plates fillet welded (arc welding). (2) Thermit process. (3) Resistance welding.	Thermit pressure process only.	(1) Thermit pressure process. (2) Flash-butt process.	…	Resistance.
…lectric arc.	Resistance welding.	…	Thermit pressure has been satisfactory ; however, with development of a portable electric flash welding unit and power plant, electric flash weld will be a more economical and a more perfect weld.	…	…
No.	Yes.	No.	Yes.	…	No.
…	Rail is heated in a specified type of portable built-up furnace with an oil-burner.	…	Thermit pressure : through use of gas torch. Electric flash : reheating electrically or gas heater.	…	…
Yes.	Yes.	Yes. Track put out of service and rails welded on ties spaced on road bed.	At site when conditions permit. Near site on flat cars when ground conditions are unsatisfactory.	…	No.
Yes.	No.	No.	Electric flash welds in shop until portable unit is available about July 1936.	…	Yes.
… rails have …n successfully …veyed over 2-ft. …ge track round …ft. radius cur…	…	…	Layout of shop will not permit welding of more than three 39-ft. rails. These rails are then conveyed to site and joined by thermit pressure method.	…	Up to the present 80 ft., but do not anticipate difficulty with 120 ft.

—	GREAT BRITAIN.			
	Great Western.	London & North Eastern.	Southern	London Passenge[r] Transport Board
QUESTION 6. — *How are the long welded rails :*				
(a) *handled when loaded?*	...	...	...	...
(b) *conveyed*	...	...	...	...
(c) *handled when unloaded?*	...	...	...	...
(d) *handled when being laid in the track?*	...	...	By hand. 40 men to a 120-ft. rail, or 12 with skids.	...
QUESTION 7. — *Are the welded joints tested in the shop or laboratory :*				
(a) *by tensile tests?*	No.	No.	No.	No.
(b) *by impact tests?*	No.	A test of a short length of rail with welded joint made some years previous to above welding of track showed that the welded joint will not stand up to standard tup test for rails.	No.	Yes.
(c) *by bending test?*	No.	No.	No.	Yes.
(d) *by examination of texture?*	No.	No.	No.	No.
(e) *by any other special examination, and if so, what?.*	No.	No.	No.	No.
QUESTION 8. — (a) *Do you adopt any method of testing the weld either in the shops or on the site without destroying the weld? (e.g. surface hardness tests).*	No.	No.	No.	No.
(b) *If so, what method is used?*	...	...	...	...

AFRICA.	JAPAN.	UNITED STATES OF AMERICA.			SOUTH AMERICA.
outh African	Japanese Government.	Bessemer and Lake Erie.	Delaware & Hudson.	Reading Co.	Central Argentine.
n skids and ramps.	...	...	Welded in long lengths (780' to 1 482') on flat cars. Handled to cars one at a time in 39-ft. lengths.	...	By crane.
wagons provi- d with pivots d skids.	...	...	Conveyed by work train to site of installation.	...	On flat wagons.
pped on level surface.	...	...	By use of small crane and gang of men, who bar rail from cars to ground.	...	Skidded.
th rail tongs.	...	...	By small crane and men with bars, lengths handled being such that can be completed between trains.	...	By manual labour.
No.	No.	No.	Yes.	...	...
Yes.	Yes.	No.	Yes.	...	Periodically .
Yes.	Yes.	No.	Yes.	...	Periodically.
Yes.	Yes.	No.	Yes.	...	...
No.	Test for determining the stresses of welded joints in service condition. (These tests are made in the Research Office of the Japanese Government Railways).	No.	Continuous deflection test to destruction. Sperry detector test.	...	Periodical hardness tests, also electrical conductivity tests.
No.	No.	No.	Yes.	...	Only surface hardness.
...	...	...	Brinell hardness and Sperry detector tests.	...	...

—	GREAT BRITAIN.			
	Great Western.	London & North Eastern.	Southern.	London Passenger Transport Board.
QUESTION 9. — *Is any welding specification issued.*	No.	No.	No.	No.
QUESTION 10. — (a) *Have you adopted any special arrangements for inspecting the welded rails in the track?*	No.	Points are fixed from which any longitudinal or lateral movement may be detected.	Technical investigation being made of width of expansion gaps at varying temperatures as well as normal daily inspection.	No.
(b) *How frequently are they inspected?*	Daily under ordinary maintenance.	Daily in conjunction with ordinary track. At intervals by technical assistant, particularly at times of varying temperatures.	Daily.	Daily.
QUESTION 11. — (a) *Has any unevenness appeared in the top surface of the rails at the joints?*	No.	No.	Some slight hollows at the welds have been noticed.	No.
(b) *If so, about what percentage of the total number of welds have been affected?*	...	...	...	...
QUESTION 12. — *Please give, if possible, a summary of fractures in or adjacent to the welds in a similar form to that adopted at the Madrid Congress (1930) for the statistical information on rail breakages (see the International Railway Congress Association Bulletin, November 1930 issue) :*				
(a) *Number of fractures.*	Nil.	Nil.	Nil.	Nil.
(b) *Number of welded joints*	...	...	...	...
(c) *Number of fractures per 100 miles*	...	...	...	...

AFRICA.	JAPAN.	UNITED STATES OF AMERICA.			SOUTH AMERICA.
...uth African.	Japanese Government.	Bessemer & Lake Erie.	Delaware & Hudson.	Reading Co.	Central Argentine.
No.	No.	No.	Yes.	...	Not as yet, the working being in an experimental stage.
...tures are re- ...ted by road ...gs.	No.	Permanent monuments were set in order to determine the longitudinal and and lateral movement of rail. Berry strain gauge tests to be made in order to compute the stress in rail due to temperature changes. Supervisor instructed to inspect track periodically.	Sperry detector test.	...	No special arrangements.
...rvising officer ...ects track eve- ...two or three ...ths.	...	Readings and measurements to be taken once a month. Supervisor's inspection to be made weekly.	Annually.	...	Daily.
No.	No.	No.	No.	...	Not as yet.
...	...	...	...	...	...
... ...k. / 60-lb. track. 37 / 80-lb. track. 67 / Total. 107	Nil.	Nil.	8	...	No fractures have yet been recorded; the number of welded joints is relatively low.
...). ...k. ...) / 60-lb. track. 16 500 / 80-lb. track. 570 / Total 21 170		...	1 402	...	...
67 / 1 530 / ...	...	...	130	...	...
...: The 80-lb. track con- ...ed of rails which were ...ly dipped at the ends. ...se ends were bent up ...h the rails cold and ... large number of frac- ...es may be due to this.		*Note:* In the original installation at Albany, seven breaks occurred through inexperience in welding. In second installation at Mechanicville, no breaks have occurred after passing through two winters. In the third installation at Schenectady, one break made of weld with rail bender; one actual break, a defective weld. In fourth installation at Windsor, no breaks have occurred. Both latter installations have passed through one winter.			

—	GREAT BRITAIN. Great Western.	London & North Eastern.	Southern.	London Passenger Transport Board.
QUESTION 13. — (a) *Do you modify the ordinary arrangement of sleepers so as to provide a closer spacing at the welded joint?*	No, ordinary spacing as for use with short fishplates.	No.	Yes.	No.
(b) *If so, please give this spacing.*	...	...	1' 4'' centres.	...
Part 3. — Expansion and lateral deformation.				
QUESTION 14. — *What are the maximum and minimum temperatures which you have found on your system :*				
(a) *in the open air?*	No records available.	18° to 60° F. since above track was welded.	20° to 100° F. (air temperatures).	20° to 130° F.
(b) *in tunnels?*	No records available.	No welded tracks in tunnels.	33° to 73° F.	60° to 80° F.
QUESTION 15. — *What rules do you adopt for determining the expansion gaps to be provided between long welded rails, in relation to their length and the temperature at the time of laying them in the track?*	Expansion gaps as for unwelded rails.	No rule. Approximately 1/2'' expansion spaces were left at each end of the welded length.	Not finally decided; rule will be based on observations of temperatures and expansion gaps.	Expansion gaps as fo 60-ft. rails.
QUESTION 16. — *What special precautions, if any, have you taken to prevent lateral deformation in track laid with long welded rails? (e.g. diagonal stays or anchoring devices).*	None.	None at present.	None, except that the use of long welded rails is at present confined to straight track. This question is receiving consideration.	None.
QUESTION 17. — *Please give the following particulars regarding the ballast in the sections of track laid with long welded rails :*				
(a) *nature*	Crushed stone or slag.	Slag.	Broken stone.	In open track; sl and limestone. tube tunnels: co crete.

·AFRICA.	JAPAN.	UNITED STATES OF AMERICA.			SOUTH AMERICA.
South African.	Japanese Government.	Bessemer and Lake Erie.	Delaware and Hudson.	Reading Co.	Central Argentine.
No.	No.	No.	No.	...	No.
...	...	...	...	...	...
25° to 140° F.	No record is kept.	— 20° to 105° F.	—25° to 100° F.	...	23° to 113° F.
No figures available.	No record is kept.	No tunnels exist.	No records of tunnels.	...	No statistics.
72' — 84' rails pansion allowce is as follows: 25° F. 3/8'' 50° F. 1/4'' 75° F. 5/32'' 100° F. 1/16'' 125° F. ıd over 0 mperatures are il temperatures)	No rules have yet been established, but in our practice the spacing is increased by 2 mm. over an ordinary one at an atmospheric temperature of 10° C. for long rails made by welding two 12-metre rails (the spacing specified for ordinary rails for this temperature being 6 mm.).	Our welded rail is one continuous stretch, one mile in length with no expansion gaps.	Use standard A.R.E.A. expansion table for 39-ft. rails for any lengths laid. We find expansion and contraction in long rails of any length when properly fastened to be approximately the same as for 78-ft. rails.	...	Rails hitherto laid are not long enough to warrant a departure from the standard.
None.	None.	No special precaution taken to prevent lateral deformation except the use of GEO construction.	Our special construction used is sufficient. Double shoulder tie plates fastened to tie by compression screw spikes independent of the rail fastening. The rail fastening is a spring steel clip which provides sufficient pressure to prevent movement of rail.	...	None.
lean gravel or hard stone.	Sieved gravel.	Limestone.	Crushed stone.	...	Stone (granite).

—	GREAT BRITAIN.			
	Great Western.	London & North Eastern.	Southern.	London Passenger Transport Board.
(b) size	1/2" to 2" or 1/2" to 1 1/2"	2"	2" to 3/4".	2 1/2"
(c) *width of ballast beyond end of sleepers (Boxing up).* .	About 10".	Welded track is situated between other tracks.	12" on the conductor rail side in electrified lines. 6" elsewhere.	9"
QUESTION 18. — *Please give the following particulars regarding the sleepers in these sections :*				
(a) *material*	Creosoted Baltic redwood.	Baltic fir.	Creosoted Baltic redwood.	Softwood in op track. Jarrah in tu tunnels.
(b) *principal dimensions.*	8'.6" × 10" (12" at joints) × 5".	8'.6" × 10" × 5".	8'.6" × 10" × 5".	Open track. 8'.6" × 10" × 5" Tube tunnels. 6'.6" × 12" × 5"
(c) *number per mile* . .	2 112	2 112	2 112 standard, 2 200 in certain experimental cases where one extra sleeper is provided per 60 ft. length.	Open track. 2 112 Tube tunnels. 1 600
QUESTION 19. — *Description of :*				
(a) *the method of fixing the long welded rails to the sleepers.*	Wood keys, cast iron chairs, two 7/8" diam. chair bolts with large ribbed washers.	Welded rails are secured to sleepers in accordance with the British standard practice for ordinary track, i.e. wood keys, cast iron chairs, and 3 chair screws. In some cases, rail anchors are added.	Wood and steel keys, cast iron chairs, 3 chair screws.	Wood keys cast i chairs. 3 chair scre
(b) *the joints between long welded rails*	Standard short fishplates with 2 bolts and joint sleepers at 1' 8 1/2" centres.	No special fittings are provided and the sleeper spacing is the same as for ordinary sleepering, i. e. 2' 7 1/2" centres.	Standard four-bolt fishplates; joint sleepers at 2 ft. centres.	Standard fishplates joint sleeper spaci
QUESTION 20. —*Have you adopted any special appliances for adjusting long welded rails?*	No.	No.	No adjustment has yet been required.	No.

AFRICA.	JAPAN.	UNITED STATES OF AMERICA.			SOUTH AMERICA.
uth African	Japanese Government.	Bessemer and Lake Erie.	Delaware & Hudson.	Reading Co.	Central Argentine.
To pass 2" diam. ring. t top of bal-, sides sloping y 1 1/4 in 1.	1/2" to 2 1/2" 9"	Minimum 3/4". Maximum 2 1/2". 1' 6" outside. 2' 3" inside.	3/4" to 2 1/2" 9"	... ...	1 1/2" to 2" 2' 6"
od and steel.	Oak (Quercus glandulifera Rl), and beech (Fagus Sieboldi Endl.).	Treated red oak.	Red oak, 6 lb., creosote treatment.	...	Red Quebracho (a native hard wood).
steel, 6' 9" × 10" 7/16"; 60-lb. steel, 3/8" × 9 1/4" × 8"; 45-lb. steel, 5 1/2" × 9" × ". s-sectional dimen- of steel sleepers n under rail.) : 9" × 4 1/2" 10" × 5".	7' 6" × 8" × 5 1/2"	8' 6" × 9" × 7"	8' 6" × 8" × 7" and 8' 6" × 9" × 7"	...	9' 0" × 9 1/2" × 4 3/4"
936 to 2 112	2 438	2 970	2 880	...	2 244 generally. 2 376 on suburban lines.
45-lb. track. spikes without plates, or steel pers with 2 bolts clips. *60-lb. track.* spikes without sole plates, or 2 coach vs and washers with or without sole es, or steel sleepers as above. *80-lb. track.* iron chair with tapered key, or steel ers as above.	2 dog spikes without sole plates.	GEO fastenings. 2 bolts and clips with sole plate screwed to tie with 4 screws.	2 bolts and spring steel clips with double shoulder tie plate screwed to tie with 2 or 4 screws.	...	100-lb. track. 2 dog spikes without sole plates, or 2 bolts and clips with sole plates, or cast iron chair with one bolt and clip and one fixed lug, screwed to sleeper with four screws.
d 4 hole fish-s; joint sleeper ng as follows: . wood, 1' 8" ng; 80-lb. steel, " spacing; 60-lb. , 1' 5 1/2" spa- 60-lb. steel, " spacing; 45-lb. , and steel 1' 5" ng.	4 hole fishplates: joint sleepers 1' 3" centres.	None. (Single welded length only).	No special joint required. Standard 4-bolt fishplate, and sole plate spanning joint ties, which are at 1' 4 1/2" centres. Lengths of rail governed only by joints for signal circuits and connections to turnouts.	...	Standard joints.
rew-operated ep adjuster.	No.	No.	No.	...	No.

	GREAT BRITAIN.			
	Great Western.	London & North Eastern.	Southern.	London Passenger Transport Board.
Part 4. — Costs.				
QUESTION 21. — *What is the cost of :*				
(a) *a joint welded by each of the methods employed?*	Only a few thermit joints have been welded and the cost was a nominal one, but might be put at 35 sh. per joint.	Approx. 30 sh. by thermit process.	28 sh. per joint (for actual welding of 20 experimental joints).	£ 2
(b) *a fishplated joint (including bonding if on electrified track)?*	About 3 sh. per joint with short fishplates and 2 bolts.	Appr. 2 sh. 3 d. (non-electrified track).	6 sh. 6 d. without bonding, 21 sh. with bonding.	4 sh. plus bonding
QUESTION 22. — *When the long welded rails are worn, do you propose :*				
(a) *to cut them into normal lengths before removal?*	...	Yes.	Yes.	Yes.
(b) *to remove them bodily?*	Yes.	Impracticable in this case.	No.	No.
QUESTION 23. — *What do you consider will be the value of worn welded rails, expressed as a percentage of the value of the corresponding weight of unwelded rails :*				
(a) *as scrap?*	100 %	100 %	100 %	No difference.
(b) *as re-usable material for secondary lines or sidings?*	100 % if re-used in 120-ft. lengths as recovered.	100 %	95 %	60 to 70 %
Part 5. — Personnel.				
QUESTION 24. — *Is the welding carried out :*				
(a) *by your own staff?*	No.	No.	No.	No.
(b) *by contractors?*	Yes.	Yes.	Yes.	By contractors assi[sted] by Railway C[o]rough labour.

AFRICA.	JAPAN.	UNITED STATES OF AMERICA.			SOUTH AMERICA.
uth African.	Japanese Government.	Bessemer and Lake Erie.	Delaware & Hudson.	Reading Co.	Central Argentine.
ut 5 sh. 6 d. 60-lb. track.	4 yen (arc welding).	$ 13.62 by thermit process.	Thermit pressure in quantity $ 10.00 per joint. Electric flash $ 10.00 experimental ; with new machine estimated $ 7.00.	...	Figures derived from experimental work could not be taken as being of value in answering this question.
6 d. for 100 % fishplates o bonding).	6.50 yen (wire bond included). 4.80 yen (welded bond included).	$ 5.28 by GEO construction.	Fishplates $ 4.00 to $ 6.00 depending upon standard used.	...	...
Yes.	This question has not yet been considered.	Not determined.	No.	...	Not yet decided.
No.	This question has not yet been considered.	Not determined.	Remove them bodily and cut into lengths convenient for handling for the scrap market. It is hoped by elimination of joints to secure full life of body of rail.	...	Not yet decided.
100 %	...	100 %	...	...	Too early to say
) % as joints be rewelded.	...	100 %	It is expected that the elimination of the joint will permit the securing of the full life of the rail in main tracks.	...	Do.
Yes.	Yes.	Yes.	First installation of thermit pressure welds by contract; others by own staff.	...	Yes.
No.	No.	Welding supervised by contract.	Electric flash welding by contract.	...	No.

—	GREAT BRITAIN.			
	Great Western.	London & North Eastern.	Southern.	London Passeng Transport Boar
Part 6. — Conclusions.				
QUESTION 25. — *Do you consider that the use of long welded rails is desirable from the point of view of comfort to passengers only, or from the point of view of economy also?*	The elimination of rail joints undoubtedly provides smoother running and in the long run would probably be an economy, but there are no figures available to substantiate this.	Insufficient data.	From point of view of comfort only; there is also a saving in the cost of maintaining the joint, but not the track as a whole at present.	Both.
QUESTION 26. — *What, in your opinion, is the maximum length of welded rail that may be laid :* (a) *in the open air?*	...	Insufficient data as yet.	No conclusion has yet been reached on this point.	No decision ye reached.
(b) *in tunnels?*	...	Do.	Do.	Do.
QUESTION 27. — *Do you intend to continue the welding of rails into long lengths?*.	...	Any decision must depend on results of present experiment and experience of others.	Yes.	Yes.

AFRICA.	JAPAN.	UNITED STATES OF AMERICA.			SOUTH AMERICA.
...uth African.	Japanese Government.	Bessemer and Lake Erie.	Delaware and Hudson.	Reading Co.	Central Argentine.
...n the point of ...w of both com- ... and economy.	Long welded rails are desirable from both points of view.	Both, especially from the point of view of economy.	Use of long welded rails is desirable from many points of view other than the comfort of passengers : (1) Saving in labour maintaining joints; (2) Longer life of rail due to elimination of joint batter, (3) Labour saving in laying rail, due to increased life; (4) Better conductivity in track circuits; (5) Elimination of necessity to bond joints; (6) Saving in maintenance of rolling stock and motive power; (7) Smoother riding track with continual pound from joints eliminated; (8) Saving in maintenance of alignement and surface by elimination of creepage and its effects; (9) With unwelded track, removal of majority of rail has been due to joint batter; with elimination of joint and loss from this cause, it may be economical to purchase more expensive and better wearing rail of alloy type.	...	Both.
...inuous rails are ...bably practic- ...e on specially ...structed track. ... definite infor- ...ion available.	78' 9'' has been experimentally adopted.	Indefinite.	In U.S. track, lengths will be governed by necessity of having insulated joints for signal circuits at signals and switches; otherwise, there is no limit to lengths either in open air or tunnels; maximum length so far laid on D. and H. : 6 900 ft. in open air.	...	Until we have had sufficient experience taking into account temperature and class of rail fastening, we cannot express an opinion.
Do.	It is thought that even longer rails can be used in tunnels, but they are not yet put in service.	Do.	Do.	...	Do.
...ar as our pre- ... experience ...s : Yes.	Yes.	Undecided.	Yes. During summer of 1936, it is proposed to weld up approximately nine miles of track, using both thermit pressure and electric flash method, as it is expected the portable electric flash welder and power plant will be available by July. Programme calls for welding of twenty to twenty-five miles of track in 1937.	...	Yes.

Group 2. — **Application of welding to**

—	GREAT BRITAIN.		AFRICA.
	London and North Eastern.	Southern.	South African.
Part 1. — Statistical information.			
QUESTION 28. — *Please give the following particulars so far as your Company is concerned :*			
(a) *Year when :*			
(1) *welded switches and crossings*	...	...	1932
(2) *welded steel sleepers were first laid in* .	1930	1931	...
(b) *Approximate total number of :*			
(1) *switches.*	Nil.	Nil.	Nil.
(2) *crossings*	Nil.	Only a few experimental ones.	About 20.
(3) *sleepers*	5 924	38 000	Nil.
(4) *any other units constructed by welding.*	Nil.	Nil.	Nil.
(c) *Number of trains per 24 hours over the section of track in which welded materials are used, carrying the heaviest traffic*	72	49	48 trains and 304 tra
(d) *Maximum axle load* . .	22 t.	21 t.	Trains 18 t. 14 cw Trams 7 t.
(e) *Maximum speed,* m.p.h.	60	65	Trains, 6. Trams,
Part 2. — Technical particulars.			
QUESTION 29. — *Have you made use of welding in the construction of :*			
(a) *switches and crossings?*	No.	Only a few experimental crossings.	Yes.
(b) *steel sleepers?*	Yes.	Yes.	No.
(c) *any other units, and if so, what?*	No.	No.	No.

struction of permanent way materials.

INDIA.	JAPAN.	UNITED STATES OF AMERICA.
Bombay, Baroda and Central India.	Japanese Government.	Delaware and Hudson.
itches only, with electrically welded stops and slide chairs, and crossings fabricated entirely by electric arc welding, laid in since 1930.	1935	...
...	...	1926
15	Some welded switches in stock, but not yet laid in track.	Nil.
13	12	Nil.
Nil.	Nil.	118/597
Nil.	Nil.	Nil.
100 electric trains.	93	Sleepers are installed in yard tracks; no record of traffic.
21 t. 9 cwt.	14.76 t.	34.93 (Engl. tons).
45	31	25
By using electrically welded slide chairs and stops for switches; By using crossings fabricated entirely by arc welding.	Yes.	No.
No.	No.	Yes.
No.	No.	No.

—	GREAT BRITAIN.		AFRICA.
	London and North Eastern.	Southern.	South African.
QUESTION 30. — *Description of welded work.*	Steel sleeper with pressed steel chairs welded on.	Steel sleeper with pressed steel chairs welded on.	Diamond crossings at inte section of railway a tramway tracks ; whe rails meet at an ang heads are welded togetl and webs joined by w ded plates ; flanges running rails and che rails are welded togetl and space between we filled by old fishpla welded.
QUESTION 31. — (a) *What methods of welding have you tried in connection with this work?*	Electric arc.	Electric metallic arc.	Electric arc.
(b) *Which have you found the most satisfactory?*	...	...	...
QUESTION 32. — (a) *In the case of electric arc welding, what is the composition of the electrode at present in use?*	...	Electrodes comply with British Standard Specification No. 538, Appendix « A ».	(Deposited metal) C. 0.8 to 1.0 % Mn. 0.55 to 0.90 % Si. 0.08 % max. P. 0.03 % max. S. 0.04 % max. Cr. 0.25 to 0.35 %
(b) *What is the nature of the coating of the electrode, if any?*	...	See above.	Heavy coated.
(c) *In the case of gas welding, what is the composition of the welding rod used?.*	...	...	Gas welding not employ
QUESTION 33. — (a) *Have you experienced any difficulty caused by shrinkage or distortion on cooling?*	...	No.	No.
(b) *If so, how have you overcome this?*	...	...	...

INDIA.	JAPAN.	UNITED STATES OF AMERICA.
3ombay, Baroda and Central India.	Japanese Government.	Delaware and Hudson.
) Stops welded to switch tongues, and brackets welded to base plates to form slide chairs;) M.S. pads welded to webs of crossing rails, and through-bars welded to pads as substitute for bolts; welded packings between webs of point and splice rails; chair brackets welded to base plates and to pads on webs.	*(a)* Stops and web plates welded to switch tongues; *(b)* Crossing rails welded to base plates, and wing rails humped by deposited weld metal.	Steel sleeper for yard tracks, constructed from two 8-ft. lengths of scrap rail at 7″ centres; scrap angle fishplates welded across ends, and sole plates welded to heads.
itches and crossings were fabricated by contractors; information not available.	Electric arc (plug or fillet welding).	Electric arc.
...	...	...
itches and crossings were fabricated by contractors; information not available.	Manganese steel (for facing wing rails). C. 0.69 % P. 0.088 % Mn. 9.28 % S. 0.005 % Si. 0.62 % Mild steel (for base plates and switch tongues). C. 0.05 % P. 0.05 % Mn. 0.36 % S. 0.008 % Si. 0.03 % High-tens. steel (for base plates). C. 0.04 % P. 0.078 % Mn. 0.71 % S. 0.034 % Si. 0.64 % Ni. 1.75 to 1.25%	(Rail ends) C. 0.25 and 14.00 % Mn. 1.25 and 1.20 % Ni. 5.00 %
Ditto.	...	Gray flux coating.
...	...	...
Yes.	Yes.	No.
ore rails are assembled to form a crossing, mild steel pads are welded o the webs, the rails being heated to certain temperature and maintained t that temperature, during every- velding operation. Splice bars and hair brackets which must of necesity be welded in position after the ails have been assembled to form a rossing, are welded not to the rails ut to the aforesaid mild steel pads o that at no time is any welding one to a rail itself in cold condition.	The distorted part of the rail is heated and made straight.	...

—	GREAT BRITAIN.		AFRICA.
	London and North Eastern.	Southern.	South African.
QUESTION 34. — (a) *Do you apply any heat treatment before or after welding?*	...	No.	No.
(b) *If so, what is done?*	...	...	...
QUESTION 35. — *Are the welded materials tested in the shop or laboratory :*			
(a) *by tensile tests?*	...	Yes.	No.
(b) *by impact tests?*	...	No.	No.
(c) *by bending tests?*	...	No.	No.
(d) *by examination of texture?*	...	Yes.	No.
(e) *by any other special examination, and if so, what?*	...	No.	Rely on skill of welder ... is specially selected ... this work.
QUESTION 36. — *Is any welding specification issued?*	No.	No.	No.
QUESTION 37. — (a) *Have you adopted any special arrangements for inspecting the welded materials in the track?*	Not beyond ordinary inspection of track.	No.	Permanent way inspe... responsible.
(b) *How frequently are they inspected?*	Daily.	Daily.	As frequently as possib...
QUESTION 38. — *Have the welded materials given as satisfactory service as those constructed in the ordinary way?*	Union between jaw and sleepers has been satisfactory.	Yes, so far as can be judged from short experience.	Better.
QUESTION 39. — (a) *Have any fractures or other defects occurred in or adjacent to the welds?*	No.	No.	Not since experiment... stage was passed.
(b) *If so, about what percentage of the total number of welds have been affected?*	...	...	...

INDIA.	JAPAN.	UNITED STATES OF AMERICA.
Bombay, Baroda and Central India.	Japanese Government.	Delaware and Hudson.
See above.	No.	No.
...	...	...
Not known.	Yes.	No.
Ditto.	No.	No.
Ditto.	No.	No.
Ditto.	No.	No.
Ditto.	No.	No.
Not known.	No.	No.
No.	No.	No.
Twice daily.	...	The same frequency as any other part of our track structure.
No.	They have not shown a satisfactory result as yet.	Yes.
Yes.	Yes; near the end of the bedplate of crossing cracks sometimes occurred in the plug weld of the rail and bed-plate, or in the flange of rail.	No.
10 %	58 %	...

—	GREAT BRITAIN.		AFRICA.
	London and North Eastern.	Southern.	South African.
Part 3. — Costs.			
QUESTION 40. — (a) *What is the average cost of :*			
(1) *a switch.*	...	...	...
(2) *a crossing*	...	...	£ 95
(3) *a steel sleeper* . .	Approx. 12/-	15/-	...
(4) *any other unit constructed by welding?*	...	...	...
(b) *What is the average cost of the same units when constructed in the ordinary way?*	(3) Wood sleeper with chairs and fastenings approx. 11/-.	(3) Chaired wooden sleeper 14/6.	(2) £ 480
Part 4. — Personnel.			
QUESTION 41. — *Is the welding carried out :*			
(a) *by your own staff?* . .	No.	No.	Yes.
(b) *by contractors?*. . . .	Yes.	Yes.	No.
Part 5. — Conclusions.			
QUESTION 42. — *Do you consider that the welded units you have used have proved successful under all conditions?*	Yes.	Yes, but cannot be used in electrified area, or where track circuits exist.	Yes.
QUESTION 43. — *Do you intend to continue the use of units constructed by welding?*	No decision yet reached.	Sleepers, yes.	Yes.

INDIA.	JAPAN.	UNITED STATES OF AMERICA.
ombay, Baroda and Central India.	Japanese Government.	Delaware and Hudson.
£ 56	139.00 yen per pair of tongue rails.	...
£ 50	243.00 yen.	..
ice is high because these are experi- nental crossings and switches fabri- ated in England.)	...	$ 3.27 complete. (Welding only, 45 cents.)
...	...	...
(1) £ 45 (2) £ 41	(1) 89.00 yen per pair of tongue rails; (2) 169.00 yen.	..
No.	No.	Yes.
Yes.	Yes.	No.
No.	No.	Yes.
Trial is still going on.	Now under consideration.	Yes.

Group 3. — **Application of welding to**

—	GRE		
	Great Western.	London Midland and Scottish.	London & Nort Eastern.
Part 1. — Statistical information.			
QUESTION 44. — *Please give the following particulars so far as your Company is concerned :*			
(a) *Year when reconditioning of :*			
(1) *rails in plain line* .	...	...	...
(2) *switches.*	1930	...	...
(3) *crossings*	1930	1932	1928
(4) *steel sleepers.* . .	...	...	...
(5) *other units* . . . *(Please state type) by welding was commenced.*	...	...	...
(b) *Approximate total number of :*			
(1) *rails in plain line.*	Nil.	Nil.	Nil.
(2) *switches.*	800 (including stock rails).	One or two.	Nil.
(3) *crossings*	6 100	14 000	8 500
(4) *steel sleepers.* . .	Nil.	Nil.	Nil.
(5) *other units.* . . .	Nil.	Nil.	Nil.
reconditioned by welding. (Successive reconditionings of the same part to count separately.)			
(c) *Number of trains per 24 hours over the section of track in which reconditioning by welding has been done, carrying the heaviest traffic.*	...	300	180
(d) *Maximum axle load,* tons	22 1/2	22 1/2	22
(e) *Maximum speed,* m.p.h.	70	90	60
Part 2. — Technical particulars.			
QUESTION 45. — *Have you made use of welding in the reconditioning of :*			
(a) *rails in plain line?* . .	No.	No.	No.
(b) *switches?*	Yes.	Only one or two instances.	No.
(c) *crossings?*.	Yes.	Yes.	Yes.
(d) *steel sleepers?*	No.	No.	No.
(e) *any other units?* . . .	No.	No.	No.

onditioning of permanent way materials.

TAIN.			IRELAND.	
Southern.	Midland and Great Northern Joint.	London Passenger Transport Board.	Great Northern.	Great Southern.
...	...	...	No information available.	...
...	1935	...	...	...
1927	1933	1930	1933	1934
...	...	...	...	...
...	...	...	...	...
Nil.	Nil.	Nil.	Not ascertained.	Nil.
A few stock rails only.	One (as a test).	Nil.	Nil.	Nil.
17 500	118	230	Not ascertained.	208
Nil.	Nil.	Nil.	Nil.	Nil.
Nil.	Nil.	Nil.	Nil.	Nil.
250	35 on main line, and continuous shunting over some crossing work.	445	42	About 200.
21	18	20	22	16
75	50	70	80	50
No.	No.	No.	Yes, to fill up defects where surface has flaked off.	No.
Yes.	Yes.	No.	No.	No.
Yes.	Yes.	Yes.	Yes.	Yes.
No.	No.	No.	No.	No.
No.	No.	No.	No.	No.

—	GRE		
	Great Western.	London Midland and Scottish.	London & North Eastern.
QUESTION 46. — (a) *What methods of welding have you tried in connection with this work*	Electric arc only.	Electric arc, oxy-acetylene in one instance.	Electric arc and oxy-acetylene.
(b) *Which have you found the most satisfactory?*	...	Arc welding.	Experience of ox acetylene is very mited.
QUESTION 47. — (a) *Do you apply any heat treatment before or after welding?*	Yes, before.	Yes, before.	No.
(b) *If so, what is done?*	Preheat to about 230° C. by electrical resistance heater.	Preheat to 200° C over a length of about 2 ft. by electric radiant heater coupled to welding generator.	...
QUESTION 48. — *Before welding is commenced what preparatory work is done :* (a) *on the rails?*	Surface to be welded is subjected to grinding and a careful examination made for the purpose of detecting cracks, etc.	Area to be welded is ground, examined by illuminated magnifying glass (× 10) oiled with kerosene and then struck with hammer. If any fine cracks show they are ground out. If cracks too deep to grind out, e.g. 1/8", are found the rail is replaced by a sound one.	Surface cracks grou out and rail clean
(b) *on the track (if the work is done in the track)?*	Timbers packed, bolts tightened and crossing generally overhauled.	Track is overhauled and surfaced, any defective fittings being renewed.	All sleepers pack and liners placed u der rail bearin where necessary.
QUESTION 49. — *What method do you adopt for obtaining a true surface after welding?*	Grinding in conjunction with the use of a steel straight edge and tyre profile gauge.	Surfaces welded are ground by abrasive wheel electrically driven through flexible shaft. Welding plant provided with auxiliary dynamo for this service. Straight-edge and templates used to check line and contour.	Surface is ground a tested with straig edge.
QUESTION 50. — *If the work is done in the track :* (a) *is it carried out between the passing of trains, or must possession of the track be obtained?*	Between trains.	All work carried out between trains without possession of track.	Between trains.
(b) *is the work done under all weather conditions, or is it suspended during periods of frost or very cold weather?*	All weather conditions.	All weather conditions except during heavy rain, snow or fog.	All weather conditions.
QUESTION 51. — (a) *Do you recondition the same rail, switch or crossing more than once?*	Yes, when necessary.	Yes.	On a few occasi this has been do
(b) *If so, what is the greatest number of times this has been done?*	...	Three times so far.	Three times.

...AIN.			IRELAND.	
Southern.	Midland & Great Northern Joint.	London Passenger Transport Board.	Great Northern.	Great Southern.
...ric arc. Oxy-acetylene welding now ...g tried experimentally.	Electric arc only.	Electric arc.	Electric arc.	Electric arc only.
..	...	...	...	...
Yes, before.	No.	Yes, before and after.	No.	Yes.
...eat by electric radiant heater to about 220° C.	...	Preheat to 240° C. and postheat to 400° C.	...	Heat applied by means of blowlamp.
...s are surface ground and tested (as ...ribed in answer to question 54) for ...ks, which if found are ground out.	Thoroughly clean off all grease and rust and grind to a suitable face.	Grind, test for flaws and preheat.	Thoroughly cleaned with wire brush.	All loose metal is either chipped or ground off.
...ers are soundly packed, cross level ...rails adjusted and wear of under...e of rails and base plates taken ... with liners welded in position.	...	Crossing bolts are tightened and crossing timbers are packed as necessary.	Sleepers are well packed and slips inserted to take up te wear on bottom of rails and chair seating.	...
...s are ground to correct relative le..., which are gauged with straight...e and template, and by means of ...areful study of the wear on the ...tly ground rails under traffic.	Grinding to template and straight-edge.	Straight-edge.	Grinding with emery wheels.	Grinding.
Between trains.	Between trains.	Dependent on nature of service and local conditions.	Between trains.	Between trains.
...pended during frost or very cold weather.	Suspended during bad weather.	All weather conditions.	All weather conditions except during hard frosts.	All weather conditions.
Yes.	Have not yet had occasion to do so, but propose doing so when necessary.	Yes.	Not unless the original weld fails.	Yes.
Limited to four times.	...	Twice.	...	Only twice, as the process of reconditioning by welding was only commenced on this system in the year 1934. It is proposed to recondition a third or even a fourth time.

—	GR[...]		
	Great Western.	London Midland and Scottish.	London & Nort[h] Eastern.
QUESTION 52. — *Are the reconditioned units tested in the shop or laboratory :*			
(a) *by tensile tests?* . . .	No.	No.	No.
(b) *by impact tests?* . . .	No.	No.	No.
(c) *by bending tests?* . . .	No.	No.	No.
(d) *by examination of texture?*	No.	No.	No.
(e) *by any other special examination, and if so, what?*	No.	No. (Only test is the test of service).	No.
QUESTION 53. — *What is the average Brinnell hardness number :*			
(a) *of the rail?*	250	About 230.	200 to 250.
(b) *of the deposited weld metals?*	250 to 300 with preheating.	About 220. *Note :* An affected zone of parent metal under the weld metal has a Brinell No. varying from 290 to 330 when rail has been preheated, and from 320 to 365 when welding has been done on a cold rail.	250 to 300 increas[...] under traffic.
QUESTION 54. — (a) *Do you adopt any test which provides a check on the soundness of the welding without destroying the weld?*	No.	No.	Yes.
(b) *If so, what test?* . . .	...	See reply to Q. 52.	In certain localiti[...] magnetic test is[...] plied to detect cra[...]
QUESTION 55. — *What special arrangements, if any, have you adopted for inspecting the reconditioned units.* (a) *on the completion of the work?*	No special arrangements.	An inspector attached to Chief engineer's office is regularly employed in making inspection of the work of each welding operative and checking condition of rail to be welded and quality of finished work.	Each batch of we[...] crossings inspecte[...] technical assista[...]
(b) *during their life in the track?*	Ordinary maintenance supervision with occasional inspection by assistant from Chief Engineer's Office.	Only part of work done is so inspected.	Inspected at inte[...]
QUESTION 56. — *Have the reconditioned units given satisfactory results as compared with new materials?*	Yes, generally speaking.	Yes.	It is difficult to [...] such a comparis[...]

[...]AIN.			IRELAND.	
Southern.	Midland and Great Northern Joint.	London Passenger Transport Board.	Great Northern.	Great Southern.
No.	No.	No.	No.	No.
[...]erimental tests have been made.	No.	No.	No.	No.
No.	No.	No.	No.	No.
Yes, from time to time.	No.	No.	No.	No.
[...]netic test on polished sections (see answer to question 54).	No.	No.	No.	No.
[...]bon rails 220; regulated sorbitic rails 305.	Not taken.	220	Not ascertained.	...
280, work hardening to 300.	Do.	250	Do.	...
Yes.	No.	Yes.	No.	No.
[...] welded surface is ground smooth [...] magnetised with a bar-magnet and [...]ispension of iron dust in methylat[...] spirit is run over it. Any cracks [...]lag holes develop opposite magnetic [...]es and attract the iron dust, which [...]ler them easily visible.	...	Magnetic inspection.	...	...
[...] welded crossings are examined as [...]ve by the welder on the completion [...] the work and again after a few [...]s.	Chief Inspector and Resident Civil Engineer follow the work closely, and watch it afterwards.	Periodic visual inspection.	Nothing more than what comes within the scope of ordinary track inspection.	No special arrangements.
[...] are subsequently inspected daily [...]the ganger and at intervals by the [...]ling staff.	...	...	...	Do.
Yes.	Yes.	Yes.	In the case of crossings, not entirely.	Yes.

	GRI		
	Great Western.	London Midland and Scottish.	London & Nort Eastern.
QUESTION 57. — *Since your present general practice has been adopted :*			
(a) *have any :*			
(1) *complete fractures* .	Yes.	Yes.	Yes, a few.
(2) *cracks*	Yes.	Yes.	Yes, some.
occurred in the reconditioned parts?			
(b) *If so, about what percentage of the total number of welds have been affected? (Current practice only; experimental work excluded.).*	0.22 % or 1 in 450. In the majority of failures, old flaws which existed prior to welding were found.	About 1 1/2 % of crossings treated have shown some defect.	Not available: al 2 000 crossings welded per annum the L. N. E. R.
Part 3. — Costs.			
QUESTION 58. — *What is the average cost :*			
(1) *of reconditioning* . . .			
(2) *of renewing*			
(a) *a rail of normal length?*	...	...	...
(b) *a switch?*	(1) £ 2. (2) £ 4/10/- (rail only).	...	...
(c) *a crossing?*	(1) £ 3-13-0 (2) £ 10 (rails only).	(1) About £ 2. (2) Cost of new 1-8 crossing without timbering or labour installing, £ 18-12-6.	(1) £ 2-15-0 (2) £ 18
(d) *a steel sleeper?*. . . .	...	..	...
(e) any other unit? . . .	...	...	...
QUESTION 59. — *To what extent does each reconditioning of a part prolong the life of that part? (Expressed as a percentage of the original life of each part.)*	...	About 20 % to 25 % if crossings are heavily worked in stations and yards. Practice to-day tends to building up slight crossing point and wing wear in fast main lines so that a good top will be preserved, and it is not yet possible to place a value on this work in terms of life per welding.	Perhaps 75 %

AIN.			IRELAND.	
Southern.	Midland and Great Northern Joint.	London Passenger Transport Board.	Great Northern.	Great Southern.
Yes.	No.	No.	Yes.	A few isolated failures of wing rails of crossings.
Yes.	No.	No.	Yes.	...
(1) 0.07 %. (2) 0.36 %.	...	...	Not yet ascertained.	...
...	...	...	No cost worked out.	...
...	(1) 7 sh. 6 d. repairs to broken point rail plus say 2 sh. 3 d. for depreciation of plant. (2) £ 4-10-0	...	...	...
£ 3-7-0 including depreciation of plant. £ 22 (rails and fittings only, including labour).	(1) £ 2 plus 12 sh. (approx.) depreciation of plant. (2) £ 13	(1) £ 3-10-0 (2) £ 15	(1) Crossing complete £ 2-2-0. Two wings only £ 1-10-0. Point and splice only 15 sh.	(1) £ 2-15-0 excluding depreciation of plant. (2) £ 30.
...	..	...	...	...
..	...	...	...	...
; not possible to give this exactly, crossings are welded a considerable e before they could be looked on as 'n out if no welding were done. For same amount of wear on a welded ' an unwelded crossing, it is expec- that the welded crossing would . slightly less than an unwelded one, rough a side-by-side comparison has been made.	Not able to say owing to short period of experience.	...	No statistics available.	About 50 to 60 %.

—	GR[...]		
	Great Western.	London Midland and Scottish.	London & Nort[...] Eastern.
Part 4. — Personnel.			
QUESTION 60. — *Is the reconditioning carried out :*			
(a) *by your own staff?* . .	Yes.	Yes.	Yes.
(b) *by contractors?*. . . .	No.	No.	No.
QUESTION 61. — *If by your own staff, what period of special training is given?*	Varies with the individual and his previous experience. Usually 3 to 4 weeks under shop conditions and a further period on the track under the supervision of a qualified permanent way welder.	Men of proved intelligence and ability are selected from track gangs and put with a welding gang (welder and grinder), and instructed in pre-grinding and finishing off. When qualified in this work the man is placed as a grinder in a gang and is instructed in the welding and operation of plant by the welder. Progress is watched by the welding inspector who sets tests of workmanship and certifies men as qualified to take charge. Formerly men were sent to a school after training, but this has been discontinued as the work given in schools does not reproduce the conditions under which the man's daily work has to be done. The track welder *must* be a good track man first and a good welder afterwards, and while a good welder can be trained in six months it takes six years to make a good track man.	Three weeks trai[...] and a period u[...] supervision in important locatio[...]
Part 5. — Conclusions.			
QUESTION 62. — *Have permanent way materials reconditioned by welding been found successful under all conditions?*	Yes, generally speaking.	In the main, yes.	Yes, under selec[...] conditions.
QUESTION 63. — *Do you intend to continue the reconditioning of permanent way materials by welding?*	Yes.	Yes.	Yes.

ITAIN.			IRELAND.	
Southern.	Midland and Great Northern Joint.	London Passenger Transport Board.	Great Northern.	Great Southern.
Yes.	Yes.	Yes.	Yes.	Yes.
No.	No.	No.	No.	No.
nonths average; the first few weeks the welding depot, and the rest of e time on the track under the close pervision of a qualified welder.	14 days.	6 weeks.	Welders received three weeks training at a welding school.	Five months.
Crossings, yes.	Yes. (With regard to switches, long switches which become damaged by derailment can successfully be repaired by electrical welding, and this is cheaper than scrapping them. One long switch has been repaired, and has been in use again two months, and up to the present it appears to be a very sound job.)	Under present procedure, yes.	Not altogether.	Crossings only have been reconditioned by welding, and they have unquestionably been a success.
Yes.	Yes.	Yes.	Crossings, yes.	Yes.

Group 3. — **Application of welding to**

	AFRICA.		
	South African.	Sudan.	Great Indian Peninsula.
Part 1. — Statistical information.			
QUESTION 44. — *Please give the following particulars so far as your Company is concerned :*			
(a) *Year when reconditioning of :*			
(1) *rails in plain line* .	1935	...	About 60 cross were reconditi by contract, in about 2 1/2 years and are still u trial. Results ar present not con red promising, cost being high only slightly less the price of material.
(2) *switches*.	...	...	...
(3) *crossings*	1932	1933	..
(4) *steel sleepers* . . .	...	...	...
(5) *other units* . . .	...	...	...
(Please state type) by welding was commenced.			
(b) *Approximate total number of :*			
(1) *rails in plain line* .	10 000	Nil.	...
(2) *switches*.	Nil.	Nil.	. .
(3) *crossings*	3 600	Some.	...
(4) *steel sleepers* . . .	Nil.	Nil.	...
(5) *other units* . . . *reconditioned by welding. (Successive reconditionings of the same part to count separately).*	Nil.	Nil.	...

nditioning of permanent way materials *(contd.)*

INDIA.			IRAQ.	JAPAN.
dras and Southern Mahratta.	Bombay, Baroda & Central India.	Burma.	Iraq.	Japanese Government.
...	...	...	Welding up of worn crossings of the built-up type has been tried (in shops only) but has not been satisfactory so far, as the rate of wear of the built up metal was rapid. The traffic on these Railways is not heavy and the crossings worn out have been in service for periods varying from 18 to 40 years, and the steel was crystallised in some cases.	1936
...	...	...	...	1936
1932	1928	...	...	1933
...	...	...	...	...
...	...	...	...	...
Nil.	Nil.	...	...	64
Nil.	Nil.	...	...	74
137	500	...	...	36
Nil.	Nil.	...	...	Nil.
Nil.	Nil.	...	...	Nil.

	AFRICA.		
	South African.	Sudan.	Madras and South Mahratta Railwa
(c) *Number of trains per 24 hours over the section of track in which reconditioning by welding has been done, carrying the heaviest traffic.*	150	Used in yards only so far.	Varies 20 to 50
(d) *Maximum axle load,* tons.	19	12	22.5
(e) *Maximum speed,* m.p.h.	45	Shunting speeds only.	60
Part 2. — Technical particulars.			
QUESTION 45. — *Have you made use of welding in the reconditioning of :*			
(a) *rails in plain line?*	Yes.	No.	No.
(b) *switches?*	No.	No.	No.
(c) *crossings?*	Yes.	Yes.	Yes.
(d) *steel sleepers?*	No.	No.	No.
(e) *any other units?*	No.	No.	No.
QUESTION 46. — (a) *What methods of welding have you tried in connection with this work?*	Electric arc.	Electric arc only.	Electric arc.
(b) *Which have you found the most satisfactory?*	...	...	...
QUESTION 47. — (a) *Do you apply any heat treatment before or after welding?*	No.	No.	No.
(b) *If so, what is done?*	...	...	...
QUESTION 48. — *Before welding is commenced what preparatory work is done :*			
(a) *on the rails?*	Rail ends lifted with a rail bender to minimise amount of welding necessary.	Grinding down to sound metal.	All surfaces to b[...] ded are ground[...]

INDIA.		JAPAN.
...bay, Baroda and Central India.	Burma.	Japanese Government.
100 electric trains.	...	93
21.45	...	15.20
45	...	31
No.	No.	Yes.
No.	Yes.	Yes.
Yes.	Yes.	Yes.
No.	No.	No.
No.	No.	No.
Electric arc only.	Electric arc.	Electric arc for facing (with manganese steel, medium-carbon steel, high-tensile steel, and mild steel electrodes), and gas-welding (with hard steel. M. W. troostic steel, and mild steel rods).
... electric arc welding has ... found successful.	...	Arc-welding in which a manganese steel rod is used is the most satisfactory. but gas-welding with a hard steel rod is better in places where the electric source is not easily obtainable, and gas-welding is economical. From the economical point of view, a mild steel rod is desirable for the track sections where traffic is not heavy, and it can well serve the purpose.
No.	Yes, before.	Not before, but sometimes after welding.
...	Preheat to 200-300° C., cooling the work slowly in ashes to avoid contraction cracks.	Half the number of faced rail ends or switch tongue rails are experimentally annealed. In some rare cases but not usually, only those crossings which are much deformed by gas-welding are annealed, because the straightening might cause cracks in the material.
...tal is ground off the area ... reconditioned.	Work hardened surface is ground off to 1/16″-1/8″.	(I) Battered rails : The battered rails are removed from track, their vertical bending is eliminated except at the battered ends, and metal is deposited on the battered parts so that their level may be true. (II) Crossings : Crossings are removed from track, and fastened by twos, back to back, in order to prevent bending, and are welded in this state. In some instances they are welded with their middle part bent a little upward. (III) Tongue rails : They are welded after being removed, straightened and again put in track. During the welding they are fastened to the stock rail so as not to bend.

	AFRICA.		
	South African.	Sudan.	Madras and Souther Mahratta Railway.
(b) *on the track (if the work is done in the track)?*	Joint sleepers packed and fish-plates tightened.	Crossings are reconditioned in Company's shops, where they are completely overhauled, and new bolts and blocks supplied.	(Crossings not recondi ned in track.) Cr sings are stripped a cleaned, and fitti renewed, the sp joints trimmed and fitted.
QUESTION 49. — *What method do you adopt for obtaining a true surface after welding?*	Grinding.	Grinding.	By grinding (welding done up to full st dard).
QUESTION 50. — *If the work is done in the track :*			
(a) *is it carried out between the passing of trains or must possession of the track be obtained?*	Between trains.	Work not done in track.	Work not done in tra
(b) *is the work done under all weather conditions, or is it suspended during periods of frost or very cold weather?*	Yes, under all weather conditions.	Do.	Do.
QUESTION 51. — (a) *Do you recondition the same rail, switch or crossing more than once?*	Yes (crossings only).	Not been in use long enough.	Yes.
(b) *If so, what is the greatest number of times this has been done?*	4 times.	...	Twice.
QUESTION 52. — *Are the reconditioned units tested in the shop or laboratory :*			Not as a regular pr dure. Occasional t of welding metal made.
(a) *by tensile tests?*	No.	No.	
(b) *by impact tests?*	No.	No.	
(c) *by bending tests?*	No.	No.	
(d) *by examination of texture?* . .	No.	No.	
(e) *by any other special examination, and if so, what?*	No.	No.	

INDIA.		JAPAN.
ombay, Baroda and Central India.	Burma.	Japanese Government.
sings are reconditioned in ntral workshop, where compo- ent parts are examined and e crossing correctly assem- ed.	Work not done in track. (Reconditioning done in workshop since crossings require attention other than reprofiling, e. g. attention to bolts, bolt holes, and fitting of splice and point rails of frog).	Arc-welding is done on the crossing in service condition after cleaning its surface. In gas-welding of the crossing, dog spikes on the sides of the middle part of crossing to be faced are pulled off, and under this part a steel plate some 12 mm. thick is placed. by means of which the rail is slightly bent upward. The welding is done in this state. Tongue rails have never been welded in service condition. A few battered rails have been welded in service condition with no preparatory work.
ding, using cross-sectional mplates, corresponding to the ofile of new rails; in addition rings are stretched along the nning edges from points well tside limits of wear at each d of wing rails; these indi- te limits between which re- forcement is necessary.	So far, grinding has been done by eye with a flexible driven carborundum wheel. Machine profiling grinder being installed which will produce accurate surfaces. The round edge will be afterwards handground.	In arc-welding, a grinder is used. In gas-welding, a finishing hammer is applied while the material is red hot. As regards gas-welding of battered rails, when the surface is rough even after the hammer is applied on it, rail files are sometimes used. The end of rail is finished by means of a chisel.
Work not done in track.	Work not done in track.	Crossing : in train intervals. Battered rail: section concerned is blocked. (Switch tongue rails not welded in track).
Throughout the year.	Do.	All weather conditions.
Yes.	Expect to do so, but the process has only been in force for six months.	No.
4 times	...	...
No.	No.	No.
No.	No.	No.
No.	No.	No.
No.	Yes.	No.
No.	Tests are made to investigate characteristics of electrodes and effects produced by preheating, annealing, etc.	Hardness test on specimen deposit.

—	AFRICA.		
	South African.	Sudan.	Madras and Southern Mahratta Railway.
QUESTION 53. — *What is the average Brinell hardness number :* (a) *of the rail?*	220	...	260
(b) *of the deposited weld metals?*	Doubtful, about 300.	...	300
QUESTION 54. — (a) *Do you adopt any test which provides a check on the soundness of the welding without destroying the weld?*	No.	No.	No.
(b) *If so, what test?*	...	...	...
QUESTION 55. — *What special arrangements, if any, have you adopted for inspecting the reconditioned units :* (a) *on the completion of the work?*	No special arrangements other than normal supervision.	No special arrangements.	No special arrangemen
(b) *during their life in the track?*	Periodical examination by permanent way inspectors and welding officer.	No special arrangements	No special arrangemen
QUESTION 56. — *Have the reconditioned units given satisfactory results as compared with new materials?*	Yes.	Not been in use long enough yet to say.	Yes.
QUESTION 57. — *Since your present general practice has been adopted :* (a) *have any :* (1) *complete fractures* . . .	Occasionally.	Not yet apparent.	No.
(2) *cracks* . . . . *occurred in the reconditioned parts?*	Yes.	Do.	No.
(b) *If so, about what percentage of the total number of welds have been affected?* *(Current practice only; experimental work excluded.)*	No figures available.	...	...

INDIA.		JAPAN.
[B]ombay, Baroda and Central India.	Burma.	Japanese Government.
185	215	207
220	280	Manganese steel . . . 350 Medium-carbon steel. . . . 321 Hard steel . . . 306 High-tensile steel . . . 185 Troostic steel . . . 176 Mild steel . . . 155
No.	No.	No.
...	...	...
By templates only.	All crossings reconditioned bear a stamped number which refers to the process used, general condition before welding, and date and position of crossing in line. All crossings are passed by a Gazetted Officer before issue.	No special arrangements (welding is done in the presence of the inspectors).
Inspected daily.	District staff are asked to keep each crossing under close inspection, and to report if necessary to the Head Office.	...
Yes.	Only the deep wear is reprofiled and the general rail head wear is allowed to remain. Such units would not be satisfactory when joined to new rails, but with average worn rails give rise to no complaint.	Yes; they are better than new materials.
Yes.	No.	No.
Yes.	No.	No.
5 %	...	...

—	AFRICA.		
	South African.	Sudan..	Madras and Souther[n] Mahratta Railway.
Part 3. — Costs.			
QUESTION 58. — *What is the average cost :* (1) *of reconditioning* . . . . . (2) *of renewing*			
(a) *a rail of normal length?* . .	(1) About 2/6 for two ends of rail.	...	...
(b) *a switch?*	...	...	...
(c) *a crossing?*	(1) About £ 3.15.0. (2) About £ 16.0.0.	(1) £ 8. (2) £ 30.	(1) Rs. 70/- per c[ro]sing including ge[ne]ral overhaul.
(d) *a steel sleeper?*	...	...	...
(e) *any other unit?*	...	...	...
QUESTION 59. — *To what extent does each reconditioning of a part prolong the life of that part? (Expressed as a percentage of the original life of each part.)*	70-75%.	Not been long enough in use as yet. (Reconditioning is yet in its early stages on this railway, but, having regard to freight costs and to the distance of this country from sources of supply, it is considered that reconditioning material by welding should lead to considerable economies.)	No information.
Part 4. — Personnel.			
QUESTION 60. — *Is the reconditioning carried out :* (a) *by our own staff?*	Yes.	Yes, in the Company's loco. shops.	By departemental st[aff]
(b) *by contractors?*	No.	No.	No.
QUESTION 61. — *If by your own staff, what period of special training is given?*	General policy is to use artisans who were apprenticed in workshops.	...	Nil.
Part 5. — Conclusions.			
QUESTION 62. — *Have permanent way materials reconditioned by welding been found successful under all conditions?*	In general, yes.	Too early to say.	Yes (crossings only)
QUESTION 63. — *Do you intend to continue the reconditioning of permanent way materials by welding?*	Yes.	Yes.	Yes (crossings only

INDIA.		JAPAN.
mbay, Baroda and Central India.	Burma.	Japanese Government.
...	...	(1) 6 yen (two rail-ends). (2) 30 yen.
...	(1) Rs. 20/- to 25/- per pair of switches. (2) Rs. 200/- per pair of switches with stock rails.	...
£ 2. £ 41.	(1) Rs. 20/- to 25/-. (2) Rs. 200/-.	(1) 30-45 yen (arc-welding). 20-40 yen (gas-welding). (2) 160 yen (1 in 8 crossing).
...	...	...
...	...	...
70 %	Uncertain.	Manganese steel rails 200 %. Hard steel rails 100 %.
Yes.	Yes.	No.
No.	No.	Yes.
e years training in general elding work before being ta- n on for this work.	Staff are drawn from welders already trained in steel fabrication. They then learn in the reconditioning shop the processes adopted.	...
Yes.	Apart from initial failures due to lack of experience, results have been satisfactory.	See answer to Q. 46 (b).
Yes.	Yes.	Yes.

Group 3. — **Application of welding to**

—	UNITED STATES OF AMERI		
	Baltimore and Ohio.	Bessemer and Lake Erie.	Delaware and Huds
Part 1. — Statistical information.			
QUESTION 44. — *Please give the following particulars so far as your Company is concerned :*			
(a) *Year when reconditioning of :*			
(1) *rails in plain line* . .	1930	...	1929
(2) *switches.*	...	...	...
(3) *crossings (or frogs)* .	1929	1932	1933
(4) *steel sleepers*	...	...	...
(5) *other units.* . . . . *(Please state type.) by welding was commenced.*	...	...	...
(b) *Approximate total number of :*			
(1) *rails in plain line* . .	310 miles of single track.	Nil.	115 500
(2) *switches.*	Nil.	Nil.	Nil.
(3) *crossings (or frogs)* .	17 000	89	10 crossings, 1 174 fr
(4) *steel sleepers*	Nil.	Nil.	Nil.
(5) *other units.* . . . . *reconditioned by welding. (Successive reconditionings of the same part to count separately.)*	Nil.	Nil.	Nil.
(c) *Number of trains per 24 hours over the section of track in which reconditioning by welding has been done, carrying the heaviest traffic.*	60	Undetermined; greater number of frogs in stalled in yards.	17
(d) *Maximum axle load,* English tons.	31.25	33.84	34.93
(e) *Maximum speed,* m.p.h. .	85	Passenger trains 55. Freight trains 35.	65
Part 2. — Technical particulars.			
QUESTION 45. — *Have you made use of welding in the reconditioning of :*			
(a) *rails in plain line?* . . .	Yes.	No.	Yes.
(b) *switches?*	No.	No.	No.
(c) *crossings (or frogs)?*. . .	Yes.	Yes.	Yes.
(d) *steel sleepers?*	No.	No.	No.
(e) *any other units?*	No.	No.	No.

onditioning of permanent way materials *(contd.)*

			SOUTH AMERICA.	
Pennsylvania.	Long Island.	Reading Co.	Buenos Ayres and Pacific.	Central Argentine.
Yards, 1918. ain line, 1930.	Yards, 1927. Main line, 1934.	1924	...	...
Yards, 1918.	Yards, 1927.	1924	...	...
anganese frogs, ain line, 1930.	Manganese frogs, main line, 1930.	1924	1935	1930
...	...	...	...	...
...	...	Angle fish-plates 1934.	...	...
) 'miles of track.	60 miles of track.	25 000	Nil.	Nil.
No data.	No data.	11 000	Nil.	A few.
manganese frogs.	100 manganese frogs.	400 (see below)	480 out of track; 390 in track.	1 100
Nil.	Nil.	Nil.	Nil.	Nil.
Nil.	Nil.	8 000 (includes fish-plates and frogs).	Nil.	Nil.
es according to location.	Varies according to the location.	45	200	200 electric trains per month. (Gross tonnage per month. 22 360 000 tons.)
37.95	30.18	31.25	22	18
75	70	80	60	60
Yes.	See under Pennsylvania RR.	Yes.	No.	No.
, in yards only.	...	Yes.	No.	Yes, but very few.
Yes.	...	Yes.	Yes.	Yes.
No.	...	No.	No.	No.
No.	...	Angle fish-plates.	No.	No.

—	UNITED STATES OF AMERI[C]		
	Baltimore and Ohio.	Bessemer and Lake Erie.	Delaware and Huds[on]
QUESTION 46. — (a) *What methods of welding have you tried in connection with this work?*	Oxy-acetylene and electric arc.	Electric arc only.	Electric arc and g[as]
(b) *Which have you found the most satisfactory?* . . .	Both in their respective fields.	...	Electric arc.
QUESTION 47. — (a) *Do you apply any heat treatment before or after welding?*	In rail end work, yes, before and after.	No.	Yes.
(b) *If so, what is done?* . . .	Preheat to 500° and after welding control cooling by preheating until ground.	...	Rail is heated with torch.
QUESTION 48. — *Before welding is commenced what preparatory work is done :* (a) *on the rails*	Nothing.	None.	Cleaned of scale, and dirt.
(b) *on the track (if the work is done in the track)?*	Surfacing, application of bars if necessary and tightening bolts.	Crossings reconditioned in shops.	Do.
QUESTION 49. — *What method do you adopt for obtaining a true surface after welding?*	Power grinding on arc and gas welds ; hand flatter on gas weld.	Grinding.	Grinding.

			SOUTH AMERICA.	
ennsylvania.	Long Island.	Reading Co.	Buenos Ayres and Pacific.	Central Argentine.
y-acetylene and electric arc.	See under Pennsylvania RR.	Oxy-acetylene and electric arc.	Electric arc only.	Electric arc.
methods econo- al. Manganese ings rebuilt with tric arc only.	...	Each in its own field; electric arc for alloy steel and oxy-acetylene for other steels.	...	...
before, in rail work with the . welding unit .	No.	No.	Arranging to do so during the coming winter; not necessary during summer months.	Not at present.
reheater is set the rail at joint be built up, and rail surface temperatu- is raised a few hundred degrees Fah- heit before the weld metal is applied.	...	...	Heating to be done with a heat element placed over the spot to be welded, obtaining current from welding generator.	...
efective metal and inations ground to good parent al before any application of weld me-	See under Pennsylvania RR.	None.	Metal ground down till fissure-free surface is obtained.	Grinding down to sound metal to eliminate cracks in cold rolled metal.
brought to good and surface, re- ned, oversized fish-plates are applied en necessary to provide drawing con- on; joint sleepers renewed if required d drainage provided.	...	Bolts tightened and joints surfaced. Angle plates reversed if wear warrants it.	...	General revision and tightening of bolts, checks, and fastenings is carried out (both in shops and in track).
ric or gas engi- driven grinding el, rim or cup el being used. rim wheel operates either on a plane d in the grinding machine and paral- to the rail head surface, or fixed ri- y in the grinding machine; the ma- e being moved horizontally back and h on the rail head surface over the led portion to secure a surface of the l metal applied even with the adja- , original rail head surface. The cup ding wheel is applied back and forth the applied weld metal, free hand; grinding wheel being driven by a ible shaft from a gas engine moun- on a wheelbarrow frame.	See under Pennsylvania RR.	Straight-edge and flatter for oxy-acetylene. Power grinder for electric arc welding.	Grinding.	Grinding.

—	UNITED STATES OF AMERI		
	Baltimore and Ohio.	Bessemer and Lake Erie.	Delaware and Hud
QUESTION 50. — *If the work is done in the track :* (a) *is it carried out between the passing of trains or must possession of the track be obtained?*	Between trains.	Work done in shops.	Between trains.
(b) *is the work done under all weather conditions, or is it suspended during periods of frost or very cold weather?*	Stopped during periods of severe cold weather.	Do.	Not done in severe w er or bad snow c tions.
QUESTION 51. — (a) *Do you recondition the same rail, switch, or crossing (or frog) more than once?*	Yes.	Generally not.	Yes.
(b) *If so, what is the greatest number of times this has been done?*	Twice, but this will probably be increased as necessary.	...	Twice.
QUESTION 52. — *Are the reconditioned units tested in the shop or laboratory :*			
(a) *by tensile tests?*	No.	No.	No.
(b) *by impact tests?*	No.	No.	No.
(c) *by bending tests?*	No.	No.	No.
(d) *by examination of texture?*	In cases of failure.	No.	No.
(e) *by any other special examination, and if so, what?*	No.	Only visible examination.	No.
QUESTION 53. — *What is the average Brinell hardness number :*			
(a) *of the rail?*	300 (cold rolled).	...	280
(b) *of the deposited weld metals?*	300 to 320.	...	330
QUESTION 54. — (a) *Do you adopt any test which provides a check on the soundness of the welding without destroying the weld?*	None, except Brinell hardness test.	No.	No.
(b) *If so, what test?*	...	...	...

			SOUTH AMERICA.	
ennsylvania.	Long Island.	Reading Co.	Buenos Ayres and Pacific.	Central Argentine.
een trains. Per- ion to use the k for the purpo- ust be obtained.	See under Pennsylvania RR.	Between trains.	Work has been done outside track, but present practice is between the passing	Between trains. to do it in track of trains.
nued through- the year, except ng season of are required for s.	... heavy snowfall when snow clearing pur-	Under all weather conditions except during storms and extremely cold weather.	Not suspended during cold weather.	Frost during working hours is exceptional, and actual welding can be delayed until frost has lifted.
Yes.	See under Pennsylvania RR.	Yes.	Yes.	Yes.
No record.	...	10 welded more than a sufficient period	Up to the present no crossing has been twice; have not to require more than	Twice. welded crossings for two treatments.
No.	Do.	No.	No.	No.
Vork done under fic; no failures occurred.	No.	...	No. completed crossing to rail when loading	Rough impact test applied by dropping about three feet on up.
other than traf-	...	No.	No.	No.
ined before and completion.	.	No.	No.	No.
No.	...	No.	No.	No.
roximately 270 cold rolled).	Do.	295 (new). 325 (cold rolled under traffic).	...	240 to 260.
40 Brinell high- an adjacent cold d parent metal.	See under Pennsylvania RR.	325 (after welding). 350 (cold rolled under traffic).	...	300 to 340.
No.	Do.	No.	No.	Does not apply to crossing reconditioning.
...	...	...	...	...

—	UNITED STATES OF AMERI		
	Baltimore and Ohio.	Bessemer and Lake Erie.	Delaware and Hud
QUESTION 55. — *What special arrangements if any, have you adopted for inspecting the reconditioned units :*			
(a) *on the completion of the work?*	Welds carefully inspected during application.	Visible examination.	No special arranger for inspection. W units are inspecte me as any other pa track structure.
(b) *during their life in the track?*	Full and complete check made of welds during their life.	Periodical supervisor's inspection.	Do.
QUESTION 56. — *Have the reconditioned units given satisfactory results as compared with new materials?*	Yes.	Reconditioning justified costs.	Yes.
QUESTION 57. — *Since your present general practice has been adopted :*			
(a) *have any :*			
(1) *complete fractures* . .	Yes.	No.	Yes.
(2) *cracks*	Yes.	No.	Yes.
occurred in the reconditioned parts?			
(b) *If so, about what percentage of the total number of welds have been affected? (Current practice only; experimental work excluded.)*	So small as to be negligible.	...	A fraction of 1
Part 3. — Costs.			
QUESTION 58. — *What is the average cost :*			
(1) *of reconditioning*			
(2) *of renewing :*			
(a) *a rail of normal length?* . .	(1) $ 1.16. (2) $ 30.00.	...	(1) Rail ends 14 inch.
(b) *a switch?*	...	...	...

			SOUTH AMERICA.	
ennsylvania.	Long Island.	Reading Co.	Buenos Ayres and Pacific.	Central Argentine.
rvisor of welding welding foreman ect the complet- work.	Do.	None.	None.	Only visual inspection.
tervals, according the density of ffic handled over the individual stret- s, to determine the necessity for a etition of the welding.	...	None.	None beyond the ordinary routine revision by P.W. inspectors.	Only general inspection of track.
and have effect- economies in the chase of new ma- al.	Do.	Yes.	Yes.	Yes.
No.	See under Pennsylvania RR.	Yes.	...	Yes.
No.	...	Yes.	A negligible amount of such cases has been experienced.	Yes.
...	...	4 %	...	2 to 3 %.
80 c. (oxy-acety- or electric arc). $ 19.50 (inclu- g other track ma- al.	(1) 90 c. (2) $ 19.50 (including other track material.	(1) $ 1.20. (2) $ 35.00.	...	. .
$ 4.00 (oxy-ace- ne). $ 32.00.	See under Pennsylvania RR.	(1) $ 2.25. (2) $ 30.00.	...	Seldom reconditioned.

—	UNITED STATES OF AMERI[C]		
	Baltimore and Ohio.	Bessemer and Lake Erie.	Delaware and Hud[-]
(c) *a crossing (or frog)?* . . .	Crossing : (1) $ 140.00. (2) $ 1 000.00. Frog : (1) $ 30.00. (2) $ 160.00.	Frog: (1) $ 28.00. (2) $ 298.00.	(1) 20 % to 40 [%] purchase value.
(d) *a steel sleeper?*	...	...	Steel ties are not r[e-con]ditioned; welding per tie as built i[n] cents.
(e) *any other unit?*	...	...	...
QUESTION 59. — *To what extent does each reconditioning of a part prolong the life of that part?* *(Expressed as a percentage of the original life of each part.)*	Rails (high speed traffic lines) 20% to 40 %. Frogs and crossings 25 % to 50 %.	Not sufficient experience.	Not definitely know[n] so many variable[s] fect the life; rails to 30 %, frogs and c[ross]ings 20 % to 40 %.
Part 4. — Personnel.			
QUESTION 60. — *Is the reconditioning carried out :*			
(a) *by your own staff?* . . .	Yes.	No.	Yes, 10 %.
(b) *by contractors?*	Yes.	Yes.	Yes, 90 %.
QUESTION 61. — *If by your own staff, what period of special training is given?*	Gas welders carefully trained as helpers before being used as welders, and their experience supplemented by welding schools. Electric welders are first broken in as helper-grinders and welders.	...	Our own staff is tr[ained] by specialists of th[e ma]nufacturers who fu[rnish] our welding sup[plies]. They are require[d to] pass welding tests [be]fore given respon[sible] work.
Part 5. — Conclusions.			
QUESTION 62. — *Have permanent way materials reconditioned by welding been found successful under all conditions?*	Yes.	Yes.	Yes.
QUESTION 63. — *Do you intend to continue the reconditioning of permanent way materials by welding?*	Yes.	Will likely continue welding of frogs.	Yes.

			SOUTH AMERICA.	
ennsylvania.	Long Island.	Reading Co.	Buenos Ayres and Pacific.	Central Argentine.
35.00 (manga- frog : electric 175.00.	Do.	(Crossing) (1) $ 40.00. (2) $ 400.00. (Frog) (1) $ 22.00. (2) $ 150.00.	(1) 45 Argentine dollars.	(1) £ 3.0.0. (2) £ 30.0.0.
...	...	...	...	...
...	...	...	...	...
: four years heavy traffic. hes : one year heavy traffic. : three years heavy traffic.	See under Pennsylvania RR.	Rail . . . . 100 %. Switch . . . 300 %. Crossing. . . 300 %. Frog . . . . 100 %.	No data yet available.	Depends on amount of wear and amount of reconditioning carried out.
Yes.	Yes.	Yes (oxy-acetylene welding.)	Yes.	Yes.
ng up of man- e castings in districts.	Some manganese castings built up by contract.	Yes (electric arc welding).	No.	No.
welder is requi- to qualify for particular work he is to do. ualify requires three to four s training. The nt must demon- e his ability be- being qualified.	See under Pennsylvania RR.	Thirty days under manufacturer's instructor, and after that periodical visits.	A month to six weeks.	Variable, about twenty days instruction in handling equipment, followed by about twenty days in shops under inspection.
Yes.	See under Pennsylvania RR.	Yes.	Crossings which have been welded have given satisfactory results.	Yes.
and are exten- the use of wel-	Do.	Yes.	Yes, crossings.	Yes.

[621. 33]

INTERNATIONAL RAILWAY CONGRESS ASSOCIATION

13th SESSION (PARIS, 1937).

QUESTION VI.

Methods and devices used, in connection with electric traction, to save current between the supply side of the power station and the driving wheels (feeders, substations, tractors), and in particular the use of mercury rectifiers.

REPORT

(Great Britain, Dominions and Colonies, India, North and South America, China, Japan),

by C. E. FAIRBURN,

Electrical Engineer, London, Midland & Scottish Railway.

INTRODUCTION.

When considering the form of questionnaire to act as a basis for this Report, the Reporter did not overlook the fact that the first consideration in the operation of a railway is to give the required service at the lowest possible total cost, and that any method of saving energy is only a means to that end if any additional capital charges and operating costs incurred are lower than the value of the energy saved. Unfortunately, in view of the extensive range of apparatus involved and the wide geographical distribution of the railways supplying information, it was thought impracticable to attempt to make a comparison of costs and the report has been confined to technical data referring to methods and apparatus.

This portion of the Report covers Great Britain, Dominions and Colonies, India, North and South America, China and Japan.

General.

In the territory concerned there can be found examples of the three systems which comprise by far the greater portion of the electrified lines in the world, i. e. low-tension direct current (L. T.-D. C.) high-tension direct current (H. T.-D. C.) and low-frequency single-phase alternating current (A. C.). The suitability of each of these systems for any particular application has been dealt with extensively in the past, but it should be remarked that many of the larger electrified railways existing today are extensions of installations carried out some time ago, so the system now in use is the same as that originally

chosen, and if such electrifications were to be carried out de novo the same system might not be chosen again.

In recent years the development of reliable mercury vapour rectifiers has given a definite impetus to D. C. systems. The still more recent production of a satisfactory mercury vapour « inverter », by removing the principal operating difficulty associated with rectifier substations when regenerative braking is used, may be considered a further advance in the use of direct current.

It still remains a somewhat difficult matter to assess the advantages and disadvantages of any particular system for any particular application in view of the technical and commercial progress which is still being made.

Concerning A. C. systems, it may be said with reasonable certainty that new polyphase applications are unlikely, while developments in phase converting devices and rectifiers carried on trains or locomotives and also in industrial frequency series commutating motors, may easily lead to the extensive employment of a 50 or 60-cycle single-phase contact line supply.

A difficulty which remains to be completely solved with A. C. systems is that of interference. It has been shown that it can be successfully and economically overcome in the case of railway and other communication circuits, but interference with radio reception in the vicinity to the track still requires a solution. The steady increase in the number of radio receivers in use will make this a factor of increasing importance.

For D. C. systems the tendency is to employ either 1 500 volts or 3 000 volts; new applications of the L. T. 3rd-rail system being limited to extensions of existing routes and cases where an overhead conductor cannot readily be erected.

The choice between 1 500-volt D. C. and 3 000-volt D. C. depends upon local conditions. The most important of these include the nature and density of the traffic and the position and number of points on the system where, to ensure ease and reliability of operation, substations should be placed, respective of purely technical considerations. Thus, in England, where a large proportion of the total traffic is suburban and where the distances between « natural » substation sites is relatively small, there is little difference in the capital and operating costs of the two voltages. In a recent instance, for a line carrying a heavy service of goods and passenger trains, the estimated differences were smaller than the limits of accuracy of the calculations involved. In many other countries where the distances between important towns are greater, the average train heavier, and the use of multiple unit stock restricted, the higher voltage may be expected to be cheaper in both capital and operating costs.

Although no single piece of apparatus employed in electric traction is responsible for so large a proportion of the total losses that its improvement or replacement could make a very great difference to the total energy consumption, the cumulative effect of small improvements in all parts could be of considerable value.

On D. C. systems and on many A. C. systems also, the least satisfactory class of device has been the rotating converter, especially of the double armature type, in use in substations. However, the mercury vapour rectifier with its low light load losses is displacing all other types of converting plant for new work on D. C. systems and the grid-controlled mercury vapour phase and frequency changer may come into general use on A. C. systems. When single-phase current is generated direct or an industrial frequency supply is used, this problem does not arise.

On the trains themselves, the energy

taken from the contact system is utilised efficiently except during starting with D. C. and polyphase A. C. equipments, but generally any energy which has to be taken from the trains on down gradients or when stopping, is wasted. On a number of lines, both A. C. and D. C., regenerative brakes which return energy to the contact line during braking on gradients are in use, but these cannot be employed to bring the train to rest. Tests now in progress on certain D. C. converting devices suggest that satisfactory solutions of this problem of starting and stopping trains without undue loss are possible.

Valuable savings in the cost of energy and in capital expenditure can frequently be effected by drawing up train timetables which give a good load factor for the system as a whole and for the substations. This matter is one which presents greater difficulties than might, at first, be expected. Much of the traffic on electrified lines is of a suburban character with two daily peaks which cannot be levelled out, while on other lines the traffic arrangements have been built up over a long period under steam operation and their alteration involved a very complete reorganisation in many departments. This can be secured only by close co-operation between the Engineering and Operating Departments concerned, after a careful analysis of the requirements of the travelling public.

Transmission lines.

The frequency and number of phases employed for railway transmission lines depend on the supply available and have little influence on the transmission losses, which are determined largely by the voltage. The minimum value which can be used is generally decided by questions of voltage drop rather than ohmic loss, while the maximum is set by the capital charges involved.

In cases where the railway transmission lines are combined with an industrial network, the total utilisation can normally be expected to be greater, thus justifying a better and more expensive construction with a resulting reduction in the loss associated with the transmission of power for the railway. Such joint use of lines appears to offer advantages, especially in highly developed areas covered by a close network of lines where little limitation is placed on the sites chosen for substations, and the multiple paths available ensure a degree of reliability comparable with that of a system restricted to railway services only. Such combined use in most A. C. traction schemes is limited, as it is impracticable to instal frequency converting equipment at many points on a railway and a special distribution network for railway use only becomes essential.

On D. C. systems, when rotating converting plant is used, the power factor in the transmission lines can readily be maintained at or about unity, while the inherent power factor of rectifiers is not so poor that a great increase in transmission loss, as compared with a device operating at unity power factor, is experienced. In consequence, on D. C. systems, devices installed purely to improve the power factor could not be expected.

On single-phase A. C. systems, locomotives employing a phase splitting or other converting device, can be adjusted to operate at unity power factor, but when commutating motors are used the power factor will always be below unity and in some cases the installation of either static or synchronous condensers is justified, especially when the power is generated as single-phase and there are no synchronous converters on the system where correction would automatically take place.

Transmission losses other than ohmic loss are not of great importance unless a very high voltage is chosen and they are largely determined by the design of

the line, i. e. dimensions of the conductors and insulators, etc. Conductors made from high tensile material enable the line span to be increased with a resulting reduction in the number of insulators required and hence in the insulator loss.

Substations.

Considering firstly substations on railways employing D. C. traction, we find that, in recent years, radical changes in the apparatus installed, in the size and in the disposition of substations in relation to the track have been brought about by the commercial development of remote control apparatus and the mercury vapour rectifier.

When plant requiring continuous superintendence is used, it is essential to concentrate it at the minimum number of points in order to minimize the wages bill involved, so on older electrified lines we find relatively large substations spaced as far apart as consideration of track distribution loss permit. The introduction of satisfactory remote control systems made it immediately possible to distribute the converting plant at a larger number of points and this process was further helped by the rectifier which is much better adapted for unattended operation than any other type of A. C. - D. C. converter.

This superiority of the rectifier arises principally from the absence of stored energy which renders synchronisation unnecessary, thereby simplifying and cheapening the control apparatus, and also makes it less liable to damage from faults on the track or to failure from disturbances on the H. T. network. It is also able to deal with short exceptional overloads without damage, and as its reliability and maximum rating have increased it has become possible to adopt an ideal layout in which each substation contains one converting unit only.

Attemps to introduce these features of low personnel costs and good plant distribution without incurring the cost of pilot cables by the use of automatic substations have not been numerous, probably owing to the lack of flexibility of such an arrangement.

Of rotating converting plant in use, the rotary converter forms the largest proportion. Occasional use has been made of motor converters while for voltages above 1 500 volts difficulties in the design of rotary converters have led to the general use of motor generator sets despite their lower efficiency.

As mentioned earlier, the rectifier is a non-reversible device and when it is used on systems employing regenerative braking, it is usually necessary to introduce additional apparatus to absorb the returned energy. Investigation of the case of city services with such braking shows that over a daily period the amount of energy actually returned to the substations is small owing to the fact that throughout the major portion of the day at any one time, on any one section of line, at least one train is motoring and absorbing energy; only at night and in the early morning when few trains are in service could voltage rises be expected and these could be overcome, where necessary and with little energy loss by the installation in the substations of loading resistances cut in and out by voltage relays. On mountain lines, frequently single-track, this method cannot be applied and if rotating converters, with their heavy losses, are not to be introduced, mercury vapour « inverters » must be adopted.

Since rectifiers and inverters installed together in a substation cannot be required to function simultaneously and as they have no essential constructional differences, an obvious economy would be to use single units incorporating the necessary switchgear to change the connections from rectifier to inverter operation. Proposals on these lines have

been made, but the present practice is to instal two almost independent units, one reason being the difficulty of preventing excessive voltage rises during the transition of a convertible unit from rectifier to inverter operation.

Grid control has been applied with equal success to all types of rectifier in use for the purposes of voltage regulation, current suppression for external fault protection and current suppression for protection against internal faults or « backfires ». It is also an essential part of the mercury vapour inverter.

There has not, however, been any widespread adoption of grid control in traction work.

Most railways have found the 4 % - 6 % regulation of the standard rectified satisfactory. A shunt characteristic in converting plant is generally preferred owing to the easier operation and better load sharing between substations, which it gives and a strong demand for grid control for voltage regulation or over-compounding is not probable.

Experience with modern rectifiers shows that the frequency of « backfires » is so low that the addition of energized grids merely for backfire protection can hardly be justified, although where they are used for some other purpose, the installation of the apparatus necessary to add this feature may be worth while.

On all railway systems of any complexity it is very desirable that the gear for protection against track short circuits should afford complete discrimination to prevent disturbances of the traffic on other tracks. This can be effected only by the inclusion of high-speed track feeder circuit breakers which renders the addition of any form of high-speed overload protection in the rectifier unnecessary, if not actually harmful. Current suppression by grid control appears, then, to have a restricted field of application only.

The probability is, therefore, that the plain rectifier will continue to be more widely used than the controlled type.

Considering the details of grid control systems, for voltage regulation and inversion, a series of synchronous positive impulses must be applied to the control grids in the correct phase relation to the supply e.m.f. for the particular load and voltage conditions obtaining. The most obvious way of generating this train of impulses is to drive a contact-making device by a synchronous motor fed from the rectifier main supply and to introduce either an electrical or a mechanical phase-shifting device to adjust the timing. This arrangement is not entirely satisfactory owing to the difficulty in preventing the synchronous motor from hunting and so introducing a cyclic variation into the timing of the impulses, further it is not an easy matter to make a phase-shifting system which is sufficiently rapid in action to follow the load changes of a traction system.

Various static systems have therefore been devised, their originators aiming at an apparatus which would generate a series of « peaky » e.m.f. waves, the phase of which would be altered directly by changes in a current (A. C. or D. C.) derived from the rectifier main circuit. Several apparently successful schemes have been worked out but they have been found not altogether satisfactory in that they are somewhat liable to be upset by harmonics in the supply system generated by the rectifier, so a third arrangement has also been used. In this the timing operation is performed by a separate phase-shifting transformer adjusted mechanically and the « peaky » e.m.f. wave is generated by a saturated transformer fed from the phase-shifting unit. Besides being more stable, this latter method appears to be more positive in its action but very rapid adjustment is not possible.

It might appear that a « peaky » wave or sharp impulse on the grids is not necessary and that a sine wave of vari-

able phase in relation to the supply e.m.f. would fulfil all requirements. This is not so, however. The minimum value of positive grid potential necessary to permit an anode to pick up current varies with load and temperature so that to obtain accurate timing under all operating conditions a rapid rise to a value above the highest minimum value experienced is necessary.

Dealing with the details of rectifier design those at present available fall into three groups, the water-cooled steel tank, the air cooled glass bulb and the low output steel tank designed to compete with the glass bulb. Types belonging to the first two groups have been in production for a considerable number of years while those belonging to the third constitute a new development. This type has not been in commercial use long enough for its capabilities to be fully demonstrated, but it appears promising.

The great majority of water-cooled steel tank units can be classed as the « top plate » type. In this construction the main anode assemblies, the auxiliary and excitation anodes, the vacuum valve and part of the cooling system are mounted on a thick steel plate which fits on the top of the rectifier vacuum cylinder and from which it can be detached for the examination of the rectifier interior. Cooling is effected by water circulating through jackets on the main cylinder and the cathode and through either an additional « condensing dome » mounted on the top plate or through an internal cooler. The top plate itself is generally provided with a water jacket or water passages and often both internal coolers and condensing cylinders are used on large units.

The pumping equipment consists of a mercury diffusion pump exhausting the rectifier and discharging at relatively low pressure into an oil sealed rotary type, mechanical pump. By placing a reservoir between these two pumps the continuous operation of the latter can be made unnecessary, even when the rectifier is in operation.

Numerous forms of vacuum seal have been evolved but only a few types have been widely used. There are two problems, one to make a joint between the insulators and the metal body of the rectifiers and the other to make a joint between the metallic parts from which the rectifier is built up. When porcelain insulators are used, the joint to the metal tank consists of a rubber or similar gasket or of an asbestos gasket made leakproof by a layer of mercury on the atmospheric side. These seals are maintained under mechanical pressure. The alternative is to make the insulator from a material which can be fused onto a metal base so that the joint on the rectifier is between metal surfaces. There are at least two satisfactory types of fused seals at present manufactured.

The metal-to-metal joints are sometimes made with gaskets or mercury seals generally similar to those employed in metal to porcelain joints or they may be of the flanged type using a sealing washer of soft metal. Satisfactory results are obtained with any of these arrangements.

Owing to the potential differences existing between the rectifier tank and cathode and between the tank and earth, there is a definite liability of excessive corrosion of the cooling water jackets, etc., unless care is taken in the design of the cooling arrangements. The closed circuit system possesses obvious advantages over the system in which the water passes once through the rectifier and then to waste. Firstly, because the cooler can be insulated from earth and maintained at or about rectifier tank potential, thus removing the larger of the two e.m.fs. tending to cause leakage currents, and secondly because the water used can, if necessary, be treated chemically to remove harmful substances and will, if the

system is correctly designed, become de-aerated and thus less active in causing corrosion.

A minor source of trouble in operation has been the failure of the high-vacuum mercury diffusion pump owing to the quantity of mercury in it being upset by distillation of mercury, either into or out of the rectifier main cylinder. In at least one design now available this is overcome by a small level equalising pipe connected between the pump boiler and a point in the rectifier.

The light load losses of a rectifier are inherently lower than those of a rotating machine, since there is no mechanical loss except that in the cooling system and in the rotary vacuum pump. These losses can be reduced to a low value by fitting a thermostat to shut down the cooler fan below a predetermined temperature, and a vacuum relay to operate the rotary pump only when necessary. It is possible to save further energy by cutting out the excitation anodes above a certain load and by using the vacuum instrument to control the mercury diffusion pump also, but these two methods tend to introduce operating difficulties and to make the plant less reliable under abnormal conditions, so they are rarely employed. By suitable design of the auxiliary anode circuit the energy consumption for excitation can be kept below 1 kW. while the consumption of a mercury diffusion pump is usually below this figure also.

The main losses, in typical low voltage designs on full load are approximately equal as between the transformer and auxiliaries and the rectifier proper, but as the voltage increases the percentage loss on the transformer remains approximately constant while the main rectifier loss decreases in almost direct proportion. Thus on 600-v. D. C. the full load efficiencies of a modern rotary converter and a modern rectifier show little difference but on 1 500 v. or 3 000 v. the rectifier possesses a definite advantage. Even on 600-v. however, the light load efficiency of the rectifier is appreciably better, so on all voltages used in traction work the all day efficiency of the rectifier is higher than that of any type of rotating converter.

The glass bulb rectifier has increased steadily in size during the years it has been manufactured and today single bulbs rated at 1 000 amps. continuously are available. The largest size in use in any numbers carries about 500 amps. continuously at low voltages (500-600-v.) and less at higher voltages; the rating of a bulb in kilowatts is generally considered to be independent of voltage above about 800 v. The device, with its absence of water cooling and pumping equipment, is thus ideally suited to cases where the output current is low and large units, incorporating a number of bulbs, have the advantage that only in the case of the main transformer can the failure of a single component put the whole unit out of commission.

There is little difference in the efficiencies of these two types as the main losses (transformer and arc loss) are much the same in each case. For small output ratings the glass bulb will show a slight advantage owing to its simpler auxiliaries.

Several forms of small steel tank rectifier have been developed experimentally in attempts to make a unit combining the advantages of the glass bulb type with the engineering features of steel construction. This involves a design in which the need for a vacuum pumping equipment and a water-cooling system have been overcome.

In the realization of this it appears to be necessary to abandon many of the features of the conventional water-cooled unit. Up to the present, somewhat greater success has been achieved in introducing air-cooling than in completely abolishing the pumping equipment.

Continuous pumping is not required in most designs but the possibility of occasional re-evacuation is still sometimes envisaged. However, the technical problems associated with the construction of a unit which would operate for years without undue deterioration of vacuum appear capable of solution. A feature of the solution seems to be that all demountable joints must be avoided, all metal to metal joints being welded and the seals made from a material which can be fused onto the metal of the rectifier. A second point is that the construction should incorporate no materials which can be damaged by high temperatures, firstly because a long « forming »or « bake-out » process at high temperature appears to be necessary, and secondly because higher operating temperatures are to be expected with air-cooling.

Air-cooled units able to carry several hundred amperes per tank are available for commercial use. In one case a permanently connected pumping equipment is supplied, and in another the tank is fitted with a vacuum valve to enable a portable pumping to be connected when necessary. In general arrangement and shape such rectifiers depart from the forms associated with water-cooled units owing to the necessity of providing as large a surface as possible for cooling. They are usually fitted with an outer sheet metal casing to direct the flow of cooling air.

To sum up, this class of rectifier appears to possess features which should make it a valuable addition to the types of converting unit now available.

The liability of a rectifier installation to cause interference with open wire communication circuits adjacent to the track or with track signalling circuits depends very much on the general layout of the line and on the contact system used. In all cases, with the possible exception of units designed for a wide range of voltage adjustments by grid control, the provision of smoothing equipment will remove any trouble experienced, but as satisfactory results are obtained in many instances without the use of filters, their inclusion in a scheme should not be regarded as universally necessary.

The easiest case is that of the 3rd and 4th contact rail system, but apart from possible interference with signal track circuits the 3rd-rail track return system is little inferior. Where an overhead conductor is used conditions are less favourable and measures to smooth the rectifier output may be necessary.

With the six-phase transformer connection commonly employed the general arrangement, when smoothing is necessary, is to fit filters for the four principal harmonic voltages, but as an alternative to the use of filters, the employment of a twelve-phase connection on the rectifier transformer is sometimes advocated. With this connection the percentage ripple present in the output is about half that occuring in the unsmoothed six-phase rectifier but is still relatively large compared to that of the six-phase rectifier fitted with filters. The connection has the advantage of giving a better power factor, but the transformer is more complicated, and there is some possibility of the rectifier becoming unstable and working as a 6-phase unit under certain circumstances when heavily loaded. Up to the present it has been applied mostly to glass-bulb installations where standard six-anode bulbs can conveniently be arranged to form two six-phase systems displaced by 30° from one another.

When trouble is experienced on a few communication circuits only on a line, it is generally cheaper to improve the balance of the affected circuits rather than to instal filters.

On A. C. systems little improvement in the efficiency of line substations is pos-

sible and the only development of importance is confined to frequency/phase converting stations, where the experimental introduction of static mercury vapour converters promises to effect considerable economies.

Several forms of converters have been suggested and a number of types tested, either under laboratory conditions or in actual service, but little information concerning the results obtained has yet been published.

In one form the converter consists of a normal rectifier supplying current to a single-phase inverter. With this arrangement there is no fixed relation between the frequencies of the two interconnected systems, so it may be used in cases where each system possesses its own generating plant and absolute frequency stabilisation is difficult. It is apparent, however, that there can be no interchange of wattless current, so synchronous rotating plant must be present on the single-phase network to supply the total wattless current required.

In other forms of converter the D. C. link is absent and the conversion takes place directly from one frequency to the other. They are characterized by the arrangement of the anodes into two similar groups, each of which carries the current corresponding to one of the half waves of the single phase supply. These two groups of anodes are sometimes in separate tanks in which case the single-phase supply can be taken from the two cathodes and sometimes in the same tank when an output transformer is essential. In some arrangements the frequency ratio is rigid but in others it is variable as in the case of the D. C. link converter, and this is the type which appears most likely to be finally adopted as it has the further advantage that it can effect an interchange of wattless current.

The introduction of remote control apparatus has given rise to less change on A. C. systems than was the case on D. C. systems. Where line substations are concerned, the low light load losses make frequent switching operations unnecessary, while the converting stations are relatively few in number and of large capacity, so the cost of maintaining a permanent operating staff is not a large item in the total expenditure.

Contact systems.

As mentioned earlier, future applications of the low-voltage D. C. third-rail or third and fourth-rail systems will probably be confined largely to special cases where physical obstacles prevent the easy installation of an overhead conductor, or where inter-running with an existing system is required. Nevertheless, any development tending to reduce losses with the system is important owing to the large mileage at present so operated.

As far as contact rails are concerned, the very low amount of wear experienced in practice makes questions of the durability of the steel chosen of secondary importance in comparison with its electrical resistance, and special qualities of steel are usually employed. Running rails, however, are always made from steels developed for their wear resisting properties.

Owing to the heavy currents obtaining in low-voltage working the question of bonding at rail joints on running and contact rails assumes considerable importance and heavy and expensive bonds were formerly found necessary, but the introduction of gas- and electrically-welded bonds has made possible both a reduction in cost and an improvement in performance. This has been particularly in evidence in cases where the design of fishplate used on the running rails has necessitated a very long bond, as the welded bond is attached to the rail head instead of to the web and can in consequence be made very short and attached immediately adjacent to the joint. Although the welded

bond shows up to greatest advantage on low-voltage systems, its use is not confined to such cases.

If the process, at present undergoing trials on a number of railways, of welding rails together in long continuous lengths for purely mechanical reasons achieves the success which at present appears possible, it will lead also to a considerable reduction in the number of bonds required.

It is the general practice, on all systems employing the running rails as the return path to bond together the rails of each track, and of adjacent tracks, at intervals depending on the magnitude of the currents involved, in order to take advantage of the service diversity on the various tracks. Where track circuiting is installed and it is not possible to give up one running rail for this purpose, such cross bonding can only be effected at the impedance bonds at the ends of each circuit, unless additional intermediate impedance bonds are specially installed; it is found that this course is justifiable in extreme cases.

Particularly on D. C. systems the conductors associated with parallel tracks are often connected together at points between substations, again to take advantage of the diversity of load on the different tracks. This practice may lead to operating difficulties under fault conditions, but these can be minimized by the installation of switches or circuit breakers in the bonding connections. A very satisfactory arrangement utilises polarized high-speed circuit breakers so connected that only the one feeding directly into a fault can open, while it recloses automatically upon the restoration of supply to the affected circuit.

In the design of overhead contact systems, the use of copper throughout has been displaced on some railways by the partial or complete substitution of copper alloys which, although of greater specific resistance than pure copper, have a considerably greater tensile strength and so enable a saving in capital cost to be effected in some instances.

Additional feeders in parallel with either the contact circuit or the return circuit are frequently used to meet special circumstances such as a long length of track fed from one end only, but it is not the general practice to use them in cases where the substations can be correctly placed when the electrification of a system is first carried out.

Locomotives, multiple-unit trains, etc.

In seeking to improve the efficiency of electric locomotives, an important point to which attention must be paid is the elimination of unnecessary weight. The weight cannot, however, be reduced below a certain value as it is essential for the driving wheels to carry sufficient weight to enable the maximum tractive effort which can be developed to be transmitted under the worst adhesion conditions normally experienced. Further, there is now no difficulty in designing motors able to develop the limiting tractive effort on wheels carrying the maximum permitted weight on any railway system, so it appears that, in general, any weight reduction on locomotives must be at the expense of that borne by the carrying and guiding wheels. Thus the possibilities of locomotive weight reduction are limited, but in cases where it can be obtained without impairing the utility of the unit the resulting saving is valuable in reducing energy consumption and in other ways.

This indicates that when considering the question, the attention of the designer must be directed to the general design of the locomotive and the determination of the minimum load necessary on the non-driving axles to ensure satisfactory riding.

Obvious methods of affecting a reduction, apart from improvements in the electrical equipment, are the use of welding and of special high-tensile steels for

the mechanical parts while the body superstructure can be lightened by methods similar to those described later for carriage stock.

There are several features in locomotive design which influence the ratio between adhesive weight and tractive effort in some degree, and attention paid to them can often result in small reductions in the necessary minimum weight.

Since the maximum tractive effort occurs at starting, when questions of riding do not arise, the expedient of transferring weight from the guiding axles to the driving axles at low speeds enables a locomotive of lower total weight to be designed for any specified duty. The complication introduced by such schemes of weight transfer is not unduly great as in many designs of locomotive, in order to improve riding qualities, there is incorporated a system of levers for axle load equalization which can be made to act as a weight shifting mechanism also, the necessary operating forces being derived from pneumatic cylinders.

The method of control of the motors at starting is also of interest. During starting the utility of a locomotive is determined by the average tractive effort and this is lower than the maximum determined by the adhesive weight owing to the limited number of steps in the control equipment. An increase in the number of steps reduces this difference and so makes better use of the weight available, but such an increase cannot generally be obtained economically by increasing the number of resistance notches or transformer tappings. It can most easily be realised by introducing a supplementary controller which passes through a complete cycle between each main controller step. Devices of this type are already in use on A. C. locomotives.

A further feature which has some bearing on the question of the ratio between tractive effort of locomotives and their adhesive weight is that of the system of drive adopted. It has been suggested, as far as this point is concerned, that the rod drive is the best but experience with recent designs suggests that some forms of individual axle drive give almost equally satisfactory results. Such individual drives are distinguished by the presence of springs giving a moderate degree of flexibility in the connection between the driving motor and the axle.

With the exception of the « gearless » drive, the disadvantages of which are well known, the conventional nose-suspended motor with single reduction gears represents the simplest mechanical arrangement available. It gives satisfactory results even in difficult circumstances and it will probably maintain its present predominant position in all applications where neither high speeds nor high powers are required. The gears fitted can be either solid or flexible, with either straight cut or skewed teeth.

The aims of designers in departing from this simple arrangement have been to relieve the axle of the unsprung weight of the motor and so to reduce track wear, to move the motor to a higher position in the frame and thus raise the centre of gravity of the locomotive in order to improve riding and to secure more space to accommodate larger motors, especially those of the double armature type.

Numerous designs have been produced, most of which make use of a sleeve or quill mounted in the locomotive frame concentrically with the normal position of the axle. This quill is driven by gears from the motor or motors; units have been built using a single gear at one end of the quill, a gear at each end of the quill and a gear in the centre, in which last case the quill may be short. The motor shafts in most instances have been horizontal, but vertical shaft designs are in use.

The simplest forms of connection between the quill and the driving axle or

wheels consist of springs so fitted that they can absorb the relative movements of the two parts due to inequalities of the track. Both leaf and helical springs are employed and satisfactory results are obtained from the arrangement in which the torque is transmitted by an increase in the compression of helical springs which are given an initial load during assembly. Some designs involve rubbing surfaces which cannot readily be lubricated but the maintenance costs are kept low by fitting renewable wearing plates of hardened steel.

In other designs the torque is transmitted by a universal link system or systems; these are usually placed between the driving wheels either adjacent to one wheel or in the centre of the axle. As no springs are incorporated in link drives, flexible gears or pinions are generally used.

One widely used link drive is an exception to the general type in that the link system and gear wheel revolve on a stub axle supported by a bracket, attached to the outside of the locomotive side frame, thus leaving the space between the wheels free and enabling a large motor to be accommodated more easily. This is a definite advantage, notably on narrow-gauge lines where difficulty is sometimes experienced in accomodating the motor.

Link drives are more expensive in first cost than the spring type and maintenance costs cannot be expected to be lower, but very good operating results are being obtained by many users. Forced lubrication systems are general but difficulty is sometimes experienced in providing adequate seals to retain the lubricant owing to the relative movement between the axle and the quill.

Rod drives are still retained in some cases for low-speed freight engines but the tendency in recent years has been in favour of the individual drive.

Where rolling stock is concerned there has been a constant demand for greater passenger comfort by the provision of increased space and improved riding characteristics of coaches. The satisfaction of these requirements by the development of known methods of construction has inevitably led to an increase in the weight of trains with a consequent increase in the locomotive power required. Some increase in weight was unavoidable, and so long at it was not disproportionate to associated benefits, was justified. The point has been reached, however, where the advantages which accrue from methods of construction which result in a lighter weight of train, without impairing the standards of comfort and safety which have been established, are generally appreciated, and some efforts in this direction have been made with almost all types of stock.

As an indication of the results which may be achieved it is interesting to note that a large main-line passenger coach which has recently been delivered to an American Railway for long-distance service weighs 37.3 tons as against 71.5 tons for a comparable conventional car. An example from stock of more normal dimensions is a European three-coach articulated unit with a weight of 73.8 tons, a reduction of 37.5 % relatively to similar all-steel stock.

As a case where considerations of special urgency apply, diesel railcars may be mentioned, for owing to the nature of the prime mover it is generally agreed that it is impracticable to use normal railway coach construction. In such a case it is not merely advantageous to develop new methods but it becomes imperative to do so.

That advantages in reduced operating and track maintenance costs will follow from weight reduction is apparent for any type of stock, but it is with regard to electric stock that the problem presents most interest, and for this there are two reasons. The first is that, as a

large part of the saving is obtained directly through reduced consumption of electrical energy, the anticipated saving of power and its costs can be calculated with assurance; the second is that the influence of weight reduction is not confined to the rolling stock, but has its effect on the capital and operating cost of the whole system including power equipment on the trains, substations, transmission lines and generating plant.

It is interesting to see roughly what it costs to haul a ton about for a year on a suburban coach :

Annual mileage	say 50 000 miles.
Energy consumption per ton-mile (including conversion and transmission losses)	say 100 Wh.
Annual energy consumption per ton	5 000 kWh.
Cost of energy per unit	say 0.35 d.
Annual cost of energy per ton of train weight	£ 7.6.0.

In addition to saving this sum, the reduction in weight of a train by one ton would enable the rating of the electrical equipment to be reduced by about 8 H.P., so saving in first cost about £ 20. This saving, together with the capitalized value of the energy saved, allowing for depreciation, is over £ 140. Further if all trains on a line were reduced in weight, the rating and cost of the substations would be substantially lower.

It will be realized, then, that the expenditure of relatively large sums on special materials and methods of construction can be justified. The actual figures will vary considerably on different services, but values of the order of £ 160 per ton are not exceptional for fast city services and it is apparent that weight reduction offers a profitable field for consideration, especially so far as electric stock is concerned.

In considering light-weight constructional methods it must not be forgotten that railway service demands a very high standard of reliability and durability, and that because of the heavy service conditions to which electric traction is frequently applied, electric stock is subjected to no less than the normal working stresses and possibly to rather more severe conditions than the average. In consequence of this it will be understood why only a gradual approach has been made in most cases.

The development which has taken place falls into two categories, one the use of materials of high strength in relation to their weight and the other, the use of improved constructional methods and designs enabling better use to be made of the materials available.

In general, non-ferrous light-weight alloys have been used in much the same manner as the materials they have replaced, the principal difference being that, especially for fittings and lightly stressed parts, a wider range of shapes and sections has become available and neater and more attractive designs have resulted. These materials are generally stressed more lightly than steel but special alloy steels are used on account of their increased strength as compared with ordinary steel and this cannot be properly exploited without abandoning stereotyped constructions.

Where changes in method are concerned, welding is probably the most important. At one time this was restricted in practice to mild steel, the three processes in general use, gas, electrode and spot welding each having particular fields of application. Improvements in technique now enable the method to be successfully applied to special alloy steels in the various forms in which they are available and in some cases to non-ferrous alloys also.

Changes in design have been directed

to two ends. Firstly, the body of a vehicle, instead of being a mere container mounted on an underframe which provides continuous support and transmits all tractive forces, is combined with the underframe in such a manner that it carries a proportion of the stresses. The body is built up in a manner resembling a tubular girder and the underframe is made of lighter section. Secondly, attention is paid to balancing the stiffness of the various parts so that, under shock stress, no one part is stressed disproportionately. This improved balance in design enables the rigidity of a vehicle as a whole to be reduced safely, with a consequent reduction in weight.

Although the influence of these changes in material and design are more apparent where bodywork and underframes are concerned, they have been applied to the construction of bogies also. Here light alloys are less in evidence and special steels, welding and carefully balanced design are more important.

Articulated stock, by virtue of the smaller number of bogies, is generally lighter than normal stock and it can frequently be used with advantage on lines where the clearances are large enough to accomodate the somewhat greater overhand on curves.

Owing to the lower axle weights and relative absence of adhesion problems, questions relating to the systems of drive employed on motor coaches are of less importance than is the case with locomotives. The nose-suspended motor, with single-reduction gear drive is almost universal, but present tendencies in design suggest that quill drives may be more widely used for high-speed units and that double reduction gears, in conjunction with higher-speed motors, may lead to some weight reduction.

Standard control systems, having about sixteen steps are satisfactory, but on certain street cars and light railways where the rate of acceleration is exceptionally high, special multi-step controllers have been introduced largely to increase the passengers' comfort. As the currents involved are low, it is possible to employ controllers of the multi-point resistance type for this purpose.

It has been shown that the complete, careful streamlining of a high speed train can effect a considerable reduction in the maximum driving power required. For this to be fully realised, attention must be paid to many points; if a locomotive is used its general shape must be considered in relation to the rolling stock and the rolling stock itself must be formed with semi-permanently coupled rakes so that the gaps between coaches can be enclosed.

Up to the present, these principles have been obeyed most frequently in the design of high speed diesel trains when the question of maximum power consumption is a matter of urgent importance. On electric trains where the available power is not so restricted and where, in general, operating speeds are lower, only partial streamlining has been adopted, possibly more with a view to improving the appearance of stock and locomotives than to reducing power consumption.

Interest in roller bearings for all classes of service is widespread at the present time and many railways are conducting experiments or have adopted them for standard use. On electrified lines they have been successfully applied on both locomotives and rolling stock for axle and armature shaft bearings. As far as energy saving is concerned, however, they do not realise any appreciable gain on sleeve bearings except at low speeds, so a reduced energy consumption can only be expected on city services with frequent stops. This saving does not appear to be of great importance as the energy loss in the bearings on such services is only a small proportion of the total energy consumption.

Ease of maintenance and almost negligible lubrication costs together with a good standard of reliability are largely responsible for their growing popularity. In fact their low frictional resistance has been found a slight drawback on some systems where there are gradients in stations, as it is then necessary to keep the brakes on until the train is ready to start thus causing some delay and in some instances jerky starting.

Train heating.

Rolling stock which is used exclusively on electrified lines is almost invariably heated by electric radiators, as the advantages of this arrangement — cleanliness, ease of control and simple maintenance — make it far superior to any system employing fuel-fired boilers.

When stock is hauled either by steam or by electric locomotives it must be fitted with the usual steam-heating system and the question arises as to whether it should be fitted with a second heating system using electric radiators, or whether the steam system should be used in conjunction with a boiler carried on the electric locomotive.

The boiler used may be either fuel fired or electric and up the present time the former has predominated. If electric heating is used, it appears to be preferable to adopt the simpler and more efficient direct system even where this involves the dual fitting of rolling stock, and the matter should be determined in practice by the relative numbers of locomotives and of coaches concerned.

For a given type of coach the energy used can be kept down to a minimum only by careful supervision, both in operation and when warming up prior to service, but the fitting of thermostats, by making the task of the train staff easier, can help matters.

The total heating load of a train is comparable in magnitude with the energy consumed for traction purposes, and in order to reduce the peak demand on the substations some railways adopt the practice of cutting out the heaters at times when the demand for power for traction is large, i.e. during acceleration or on heavy gradients.

Regenerative braking.

Up to the present time, regenerative braking has been employed only on lines having heavy gradients, for the purpose of controlling the speed during descents and with the apparatus used it is not possible to bring trains to standstill. The value of the energy returned to the line is considerable in many instances, but the primary reasons often given for the use of the system are the big reduction in wear on the friction brake, the additional safety imparted by the fact that the friction brake is reserved for emergency use, and the higher operating speeds which are possible.

Applications of regenerative braking can be found on lines using single-phase and three-phase alternating current, and direct current. It is an inherent and very satisfactory feature of three phase-systems and of « phase-splitting » locomotives on single-phase lines. In other cases additional apparatus is needed. Completely satisfactory results are obtained on D. C. lines but on single-phase lines where commutating motors are used, although the technical problems involved have been solved, operating difficulties have tended to restrict development.

As mentioned earlier, tests are in progress on certain special D. C. converted devices which enable trains to be braked regeneratively to standstill and which also take the place of the usual starting resistances, thus effecting a double economy in energy. In the case of fast suburban services it is stated that this can amount to a total of 40 % or more.

In one type, which has been successfully applied to multiple-unit trains, the

voltage supplied to the motors is varied from zero to maximum by a small field regulator. The control gear required is thus very simple and it is claimed that the addition of the converter reduces rather than increases the maintenance of electrical equipment on the train.

Such converters impart other advantages in the form of ease of control and smoothness of acceleration and deceleration. Their application appears to be limited to suburban services; there is no obvious way in which they could effect appreciable economies on long-distance trains, and the carrying of the additional weight could hardly be justified, except perhaps on lines with heavy gradients where they could be used to regulate the speed as well as to stop and start the train.

Summary and conclusions.

Introduction and general.

When considering the introduction of improved apparatus or methods of working, capital charges, savings in maintenance and in energy consumption, and convenience of operation, have to be taken into account. The primary purpose of this report is to survey the possibilities of effecting savings in energy consumption.

Although on established electrified lines radical changes in the system used can hardly be envisaged, the question of choice of system is of interest. The mercury vapour converter has enhanced the position of D. C. systems in recent years, but developments in the equipment of low-frequency single-phase lines such as the mercury vapour phase/frequency converter, and the introduction of industrial frequency single-phase lines, have also improved the position of alternating current systems.

There are two ways only by which substantial reductions in energy consumption might be brought about. The first and most important is by the direct method of reducing the propulsive power required by the adoption of light-weight stock and the second is by the use of regenerative brakes for stopping trains.

The former method appears to have received some attention from most Railways, but, in view of the value of the savings which could be expected in many instances, relatively little progress seems to have been made. The latter method, which would be of greatest value on suburban services, is still in the experimental stage, although extensive trials are being carried out on at least one important system.

With regard to improved methods of working, difficulties met in attempts to arrange train working times to give a good system load factor are often surprisingly great, owing to the inflexibility of the traffic carried and of the Railway organisation itself.

Transmission lines.

There seems to be no great possibility of effecting appreciable savings in energy loss in railway distribution systems, but attention should be paid to the question of capital cost, and in particular to the possible reduction in certain cases resulting from the use of a combined industrial and railway system.

Apparatus for power factor correction to reduce transmission losses is to be expected more frequently on A. C. than on D. C. systems owing to the relatively good values of power factor experienced with most types of A.C./D.C. converting plant.

Substations.

On D. C. systems, firstly the introduction of remote control apparatus and secondly the development of the mercury-vapour converter have brought about fundamental changes in substation practice and have made possible the adoption of closely spaced single-unit substations with their attendant advantages of low track loss and reliability.

In comparison with other types of converter, the rectifier suffers from one limitation, its unidirectional characteristics. This restriction may be overcome, when necessary, in several ways, but the only one which can be regarded as universally applicable and which preserves the advantages of rectifier operation is the installation of mercury-vapour inverters.

The fitting of rectifiers with control grids for voltage regulation or protection against internal or external faults appears to be of limited application in traction work, but satisfactory types of apparatus have been developed for these purposes.

Rectifiers are commercially available in three forms, the water-cooled steel tank, the glass bulb, and the recently introduced low-output steel tank. The constructional and operating features of the first two types are well known but a true assessment of the value of the last type cannot be made owing to the short time that it has been offered by manufacturers; it appears to be a valuable addition for certain applications.

Emphasis must be placed on the fact that interference from rectifier installations with communication and signal circuits should not be expected in all cases, and that the provision of output smoothing gear should not be regarded as universally necessary.

On A. C. systems, the experimental use of mercury-vapour phase/frequency converters is the most important recent contribution to the improvement of substation efficiency; several types have been proposed and a number of experimental units installed. Other technical changes of the last few years such as the use of remote control apparatus, have influenced D. C. substations more than A. C. substations.

Contact systems.

In the case of both running rails and contact rails, the substitution of welded bonds at the rail joints for the mechanical types previously used has made possible a reduction in first cost and an improvement in performance. This is of special value on low-voltage systems but it is not confined to such cases.

The usual bonding of adjacent rails and tracks to secure a lower resistance return path cannot normally be carried out on lines where track circuiting is in use except at the impedance bonds at the ends of the sections. In cases where the sections are long and the currents involved heavy the addition of special intermediate impedance bonds between the ends of sections for the purpose of effecting more frequent bonding of tracks may be justified.

Further reductions in energy loss may be obtained by connecting parallel supply conductors together at points along the track but this sometimes causes operating difficulties under fault conditions, and the remedy frequently adopted is to make the connections through switches or circuit breakers.

There is, perhaps, some tendency to use heavier conductor rails on 3rd-rail systems where the usual substation spacing is already small, but on overhead systems, with their higher voltage, the general trend is to reduce both the substation spacing and the conductor size. This latter change can be attributed to the adoption of mercury rectifier substations.

Locomotives, multiple-unit trains, etc.

The demand for locomotives of greater speed and power by a number of Railways has caused interest to be directed to various design features. Of these, systems of weight transfer and of fine regulation of current to give easier starting and various types of individual axle drive are of definite interest.

In the case of coaches and rolling stock, where weight reduction is very desirable, serious attempts to effect a large improvement appear to have been

made by some Railways. These attempts have been concerned with the design of all classes of rolling stock, and it can readily be shown that expenditure on lighter methods of construction is profitable, particularly in the case of suburban multiple-unit stock.

The various methods used can be divided into two categories, the use of special materials (high-tensile steels, aluminium alloys) and special constructional methods and designs (use of welding, combined body and underframe, better distribution of shock stress), while attention has been devoted to the lighter weight of articulated stock.

When motor coaches are concerned, the method of drive and the type of control equipment (excluding regenerative types) have little bearing on energy consumption.

Streamlining of electric locomotives and rolling stock has made some progress but this appears to be due to the resulting improved appearance rather than to the energy saving effected, which is not of great value at the speeds commonly attained by electrified stock.

Roller bearings are widely in use, but again not so much for the primary purpose of saving energy, but to secure lower maintenance costs.

Train heating.

Coaching and multiple-unit stock used exclusively on electrified lines is universally heated by electric radiators. Steam heating systems using either fuel-fired or electric boilers are adopted only on stock which must sometimes be drawn by steam locomotives, and even here it is often better to equip the stock for both steam and direct electric heating.

Regenerative braking.

Regenerative braking systems may be divided into two classes, those used on heavily graded lines to control the train speed, and those used to bring the train to rest for normal service stops. The former are well developed on all classes of locomotives except the single-phase commutating type where practical difficulties have retarded development. The second class is only in the development stage but promising results are being obtained on D. C. systems and extended use may be expected in certain cases.

An important advantage of some types is that the converters are used during starting as well as during stopping thus dispensing with the usual starting resistances and saving the losses which occur in them.

They are thus best suited to suburban trains; it seems doubtful whether they could be successfully applied to long-distance trains.

SUMMARY OF REPLIES TO QUESTIONNAIRE.

A. — General details of electrified lines.

Sixteen of the replies received give data relating to electrified lines.

The lines concerned are :

3rd-rail D. C. system :		
Baltimore & Ohio Railroad	650 v.	4 route-miles.
Buenos Ayres Western Railway . . .	800 v.	28 » »
Central Argentine Railway	825 v.	42 » »
Great Western Railway (Gt. Bn.) . . .	600 v.	9 » »
London Midland & Scottish Railway . .	600 v.	
(3 independent lines)	650 v.	92 » »
London Midland & Scottish Railway . .	1 200 v.	14 » »

London & North Eastern Railway: (Tyneside Lines)	600 v.	32 route-miles.
Long Island Railroad	650 v.	129 » »
Southern Railway (Gt. Bn.)	660 v.	540 » »
Staten Island Rapid Transit Railway	650 v.	22 » »
Overhead conductor, D. C. system:		
Bombay, Baroda & Central India Railway	1 500 v.	21 » »
Great Indian Peninsula Railway	1 500 v.	183 » »
Japanese State Railways: (5 independent lines)	600 v. & 1 500 v.	361 » »
London Midland & Scottish & London & North Eastern Railways	1 500 v.	9 » »
New Zealand Government Railways: (2 independent lines)	1 500 v.	15 » »
South Indian Railway	1 500 v.	18 » »
South African Railways and Harbours	3 000 v.	380 » »
Overhead conductor single-phase 25-cycle system:		
Long Island Railroad	11 kV.	12 » »
Pennsylvania Railroad	11 kV.	373 » »
Reading Company	12 kV.	84 » »

These figures do not include extensions which are planned or under construction.

The annual power consumption for all railway purposes on the various groups of lines ranges from 4.2 to 448 million units and the consumption per route-mile per annum for traction purposes from 0.26 to 2.1 million units. The average consumption per route-mile is almost exactly one million units or 0.475 million units per track-mile, based on the estimated track mileage excluding sidings.

There are only two Railways which generate all energy required, but there are five independent lines where all power used is generated by the Railway. On extensive systems purchased power is received at more than one point.

Load factor figures are given in most replies. Based on 30 min. maximum demand the lowest value for a complete system is 26 % and the highest estimated at 55 %.

Power factor figures are given in thirteen replies. On D. C. lines they vary from 0.9 lagging to 0.96 leading and on A. C. lines from 0.72 lagging to 0.9 lagging.

Four railways make a serious effort to relate the timetables to the electrical load in an endeavour to improve the system efficiency by securing a better load factor.

B. — Transmission lines.

With the exception of two cases where there is a single substation only and another where direct generation is adopted, a H. T. distribution system is run alongside the track, and when a purchased supply is taken at more than one point, the supply lines, in general, form part of the distribution system.

On four lines the railway transmission system is combined with an industrial network.

The transmission on D. C. lines is, in every case, three-phase, the voltage varying from 5.0 kV. on part of a short line, to 110 kV. on part of an extensive system, while 154 kV. will be used on a transmission route under construction. On the three A. C. lines, single-phase

transmission at 22, 36 and 132 kV. is used.

Estimated or measured transmission losses are given in thirteen replies, they range from 0.5 % to 9.6 %. The figure of 0.5 % is exceptionally low and occurs on a short duplicate heavy section line. No other figure is below 1.5 %.

The maximum voltage drop in the H.T. distribution system under normal operating conditions is stated to vary from a negligible amount to 21 %. This high value is exceptional, the next highest figure is 13 %.

In seeking to minimise transmission losses, no companies have stated that they have introduced any novel devices, but in all cases care is taken to operate the system in an economical manner, e. g. the distribution of load between multiple feeders and supply points is regulated and the plant in commission is adjusted to actual requirements.

The converting equipment in D. C. substations has an inherently good power factor and on no system are synchronous condensers found necessary for power factor improvement, but they will be used in conjunction with a 154-kV. transmission line now under construction.

On A. C. systems, in view of the relatively poor power factor of the series commutating motor, it has been found desirable to instal synchronous condensers in two cases, and in one of these instances, the generators of phase/frequency converters, when not on load, can be run light as condensers.

C. — Traction substations.

The average distances between substations on D. C. systems are :

System Voltage.		*Route miles between substations.* Lowest fig.	Highest fig.	Average.
600-650	(9 lines)	2.1	4.6	3.4
800-825	(2 lines)	4.6	7.0	5.8
1 200	(1 line)	—	—	7.0
1 500	(8 lines)	4.5	12.3	8.5
3 000	(1 line)	—	—	14.0

The three A. C. systems have supply points at average intervals of 12, 54 and 84 miles and auto-transformer stations at 3.0, 9 and 8 miles respectively.

With two exceptions, all systems having more than four substations make some use of remote control apparatus. In the case of one exception a change to remote control is intended; the other is the Japanese State Railways, where the entire system of 39 substations is operated manually. On nine D. C. lines all substations, with the possible exception of the control substation, are operated by remote control.

On the three A. C. lines, the transformer substations are all operated by remote control, but phase/frequency converters and synchronous condenser plant is still generally manually operated.

The minimum momentary overload rating for A. C. - D. C. converting plant of recent design is 200 %. In some cases 50 % overload can be carried for 2 hours, while at least 25 % overload can be carried for the same period in almost all cases. On only one system is plant with short-time overload capacity being installed.

In the case of all D. C. systems the amount of substation plant in use is adjusted throughout the day to the load demand either locally or by remote control equipment where this is provided. On a portion of one system where the substations are of the single unit type changes cannot be made, however.

Of the 3 single-phase alternating current systems, one only operates frequency/phase converting equipment and as

a single set only is installed no adjustment is possible. A frequent alteration in the number of transformers in use would hardly be justified by any resulting economy and on one system such changes are made at weekly intervals to meet seasonal variations in traffic, while on another the only step taken is to reduce the number of step-up transformers during the night.

The efficiency figures available are too few in number and cover too wide a range of rating to enable accurate comparisons to be made; on 600-800-v. D. C. the average overall full load and half load figures for rotary converters are 94.0 % and 92.7 %, and for rectifiers 94.5 % and 94.7 %. On 1 500-v. D. C. rotary converters average 94.3 % and 92.3 %, and rectifiers 95.7 % and 95.3 %.

On the Natal section of the South African Railways, where regenerative braking is employed, 3 000-v. motor generator sets are in use, but the latest converting plant consists of rectifier-inverter units. The overall full load efficiency of the older sets is 89.6 %, and of the newer 96.4 %. Each converter comprises separate rectifier and inverter units; both are supplied with grid control equipment, which provides voltage regulation, arc suppression and back-fire prevention, in addition to its essential function in the inverter unit.

The few instances where rectifiers have displaced existing converting plant have arisen under modernisation schemes and the change has not been made merely to improve the system efficiency.

Few substation efficiency figures for rectifiers are given. Apart from the control of coolers and fans by the rectifier temperature or load and the mechanical vacuum pump by the state of the rectifier vacuum, no attempt is made to reduce auxiliary losses by the addition of non-essential control devices.

Heaters, either internal or external, are fitted to some rectifiers on most systems using such plant but they appear to be restricted to early types. The temperatures at which full load and momentary rated overload can be carried varies considerably, being as low as 5° C. in the best case and as high as 15° C. for full load, and 25° C. for momentary overload in the worst case.

No trouble has been reported anywhere from frequent « back-fires » and none at all have occurred on some lines during several years' operation. Back-fires which have occurred have often been associated with a newly formed rectifier or an exceptional load, but frequently the circumstances have not been clearly established.

Some internal short circuits are reported as caused by incorrect timing of the grid impulse apparatus on the South African converters, when they were first put into service. These are the only units with grid control in service on the lines under review, but the rectifiers being installed on the Reef lines of the same Railway will have energized grids for arc suppression and back-fire prevention.

The full-load power factor of rectifiers is stated to lie between 0.91 and 0.95 but no special attempts to measure it accurately have been made, nor have special instruments been introduced for the purpose.

No instances of interference effects due to harmonics in the input current of rectifiers have been noticed and only in a limited number of cases have ripples in the output current made the fitting of output filters necessary. In one case the provision of filters was avoided by improving the balance of nearby communication circuits. Some filters are used by four railways while two make no such provision.

The grid-controlled rectifiers mentioned above are included in those having output filters; these have successfully

overcome telephone interference, but radio interference does not appear to have been eliminated as yet.

Two railways, in addition to the South African Railways, use regenerative braking. In both cases, the system is 1 500-v. D. C. and substations are equipped with rotary converters. On one railway reverse power relays are fitted to short-circuit the series field windings, while on the other railway the only special steps taken have been to instal high-speed circuit breakers to operate on excessive reverse power, and meters to measure the reverse power received.

No reply describes any novel three- to single-phase converting plant for A. C. substations, which in one case only is owned and operated by the Railway. On all three lines the transmission voltage is higher than that of the contact line and step-up transformers are installed at the supply points.

D. — Contact systems.

On lines using a 3rd rail or 3rd and 4th rails, the manufacture of the steel used is controlled to secure a low resistance and frequently a heavy section is adopted. The maximum size used is 150 lb./yd., and in three instances only is it stated to be less than 100 lb./yd. In two of these cases the track voltage is 825 v. and 1 200 v. high, while in the third, heavy positive and negative feeders are installed. Bonding of conductor rails is usually effected with pressed or pin type bonds, but welded bonds are being used, either experimentally or as standard by three railways. On most lines the conductor rails belonging to parallel tracks are connected at intervals, frequently through isolating switches or circuit breakers.

On overhead conductor systems the total equivalent copper section used on 1 500-v. lines varies from 0.25 sq. in. to 2.78 sq. in., but on long main lines the limits are 0.45-1,4 sq. in. On the 3 000-v. line the minimum section is 0.4 sq. in. (32 % of route mileage) and the maximum 1.25 sq. in. (9 % of route mileage). Parallel feeder cables are used to a very limited extent only, and on six lines adjacent track overhead conductors are bonded between substations either solidly or through circuit breakers. No such bonding is adopted on two systems.

On single-phase A. C. systems a section of 0.26 sq. in. is employed for the whole of one line and for a large percentage of the other two lines where, however, smaller sections are used in some places and in sidings. No bonding of conductors between transformer substations is carried out.

On all systems the general practice is to make the contact circuits between substations continuous so that each length has a double feed.

Where the running rails form the return circuit the bonds, as in the case of conductor rails, are generally of the pressed type but either standard or experimental use of welded bonds is mentioned in six replies.

Gas welding appears to be the process generally adopted for conductor and running rails; no reference is made to electric welding.

Cross-bonding of tracks is adopted on all lines; on conductor rail systems at intervals varying from 150 ft. to 1 000 ft.; on 1 500-v. D. C. systems from 150 ft. to 10 000 ft.; on the 3 000-v. D. C. systems at 330 ft., and on single-phase A. C. systems from 5 000 to 10 000 ft. or at the ends of signal track circuits. Track circuiting involves the omission of bonds in some places but on one low voltage system additional impedance bonds are added where necessary to prevent the interval exceeding 1 320 ft.

On 3rd-rail lines negative feeders are used to some extent in three cases and in a further three an uninsulated 4th rail has been laid in places, in one instance where one running rail is given up for

track circuiting. On one line guard rails are bonded to the running rails.

On the 1 500-v. lines, two make use of negative feeders in each case on lengths of track fed from a single point.

On the A. C. systems, one uses no additional conductors, one uses negative feeders in several places where the substation spacing is large, and on the third an earth wire carried on the overhead structure is connected to alternate impedance bonds. No use is made of earth plates on any system to reduce the resistance of the return path.

Estimates of the loss in the track system are given in nine replies and vary from 1.5 % to 10 % of the substation output on 3rd-rail system. One 1 500-v. system gives 1.5 % and another 2.0 %, while the South African Railways estimate 7 % for 1 500-v. and 3 000-v. lines. On none of the three single-phase systems does it exceed 1 %.

E. — Locomotives, multiple-unit trains, etc.

Information concerning locomotives was given in nine replies. In two cases an endeavour to reduce the weight has been made, in one by the general employment of welding and in the other by using cabs of either welded steel or of riveted aluminium construction.

The motor speeds and gear ratios used are :

Motor speed. (1-hr. rating, full field).	*Ratio.*
468 r.p.m.	5.44 : 1 (low speed freight loco., A. C. motor)
485 »	3.89 : 1.
537 »	4.15 : 1.
600-800 r.p.m.	2.63-3.45 : 1 (passenger). 3.41-4.77 : 1 (freight).
604 r.p.m.	3.66 : 1.
650 »	4.94 : 1.
660 »	4.41 : 1.
689 »	3.74 : 1.
1 250 »	2.94 : 1 (90 m.p.h., A. C. motor).
1 910 »	3.59 : 1 (90 m.p.h., A. C. motor).

Two of the railways have some locomotives with rod drive and one uses a buck and boost transformer to give fine control of the motor current.

Streamlining of locomotives is adopted, generally to a limited extent, on four railways to secure an improved appearance rather than to reduce wind resistance.

No experiments with rectifiers carried on locomotives have been made on the lines under review.

On motor coaches and multiple unit trains, details of which are given in fifteen replies, weight reduction has been effected by welding, articulation and the use of aluminium. In two cases stock under construction will incorporate combined welded bodies and underframes, and on one railway, which had previously made up multiple-unit trains from single coach units, the introduction of trailer units has led to a reduction in the total weight of electrical equipment.

The motor speeds and gear ratios are :

Motor speed. (1-hr. rating, full field).	*Ratio.*
510 r.p.m.	2.08 : 1.
580 »	2.36 : 1.
592 »	3.13 : 1.

600-800 r.p.m. . . .	2.04-2.52 : 1.
610 r.p.m.	2.81 : 1.
632 »	3.18 : 1.
642 »	3.33 : 1.
645 »	3.23 : 1.
650 »	2.48 : 1.
660 »	3.57 : 1.
663 »	3.33 : 1.
670 »	3.33 : 1.
720 »	3.28 : 1.
734 »	3.94 : 1.
745 »	3.42 : 1.
830 »	3.94 : 1.
838 »	4.33 : 1.
864 »	2.85 : 1 (A. C. motor).
890 »	2.21 : 1 (A. C. motor, cont. rating).
900 »	2.59 : 1 (A. C. motor).
1 120 »	2.59 : 1 (A. C. motor, cont. rating).

In all cases a single reduction gear drive with nose suspension of the motors is used, the gears fitted to A. C. motors being of the flexible type. The use of a current limiting relay to regulate the starting current is mentioned in ten replies but no special devices to give fine regulation have been introduced.

A number of railways build the stock with rounded ends but otherwise no progress in streamlining is reported.

Roller bearings, for motor armatures and/or axle journals, are used to some extent by six of the Railways and in three instances they will be fitted to stock or locomotives now under construction.

The heating of multiple unit trains where it is required, is carried out by direct electric heaters, in every case but apparently steam for the heating of main line stock is usually generated by fuel fired boilers. One railway has two locomotives fitted with electric boilers.

The practice of cutting out the heaters on trains during acceleration is followed on one railway, and is being considered by a second. With one exception, the train staff have control of the heating but this is supplemented by thermostats on four Railways and is being adopted for new stock by a further three. On one line thermostats are used to control lavatory water heaters.

Where thermostats are not provided, it is sometimes the practice to give instructions to the train staff for the switching on or off of heaters by notices exhibited at certain points along the route.

The percentage of energy used on the railway which is required for heating is estimated to be from 4 to 10 % in England, from 2 % to 10 % in U. S. A. and 2 % in Japan.

Three of the replies give details of regenerative braking equipment on locomotives.

On the Great Indian Peninsula Railway the freight locomotives are fitted with regenerative brakes which control trains on gradients of 1 % to 2.7 % without the assistance of the mechanical brakes. The weight of the additional equipment required is 3 tons per locomotive and 50/55 % of the available train energy is recovered when the brakes are in use.

On the Japanese State Railways regenerative braking has recently been adopted on a mountainous section of line about 50 miles in length where gradients

of 1 in 40 exist. It is used in conjunction with air and hand brakes and about 30 % of the energy used on the locomotive is returned to the overhead line. The additional apparatus weighs approximately 1 ton.

On the Natal section of the South African Railways the regenerative brake is used alone on gradients of 0.4 % to 3.5 %, and about 6 % of the energy sent out from the substations is reconverted to A. C. The additional apparatus weighs 2.75 tons per locomotive unit, but as the gradients are generally in one direction no increase in the motor size has been required.

In conclusion, the Author would like to thank the Railway Executives who have supplied the information on which this Report is largely based.

(See overleaf : Summary of individual replies of Railway Administrations covered by this report.)

Single-phase alternat

—	Long Island.
A. General details of electrified lines.	
1. *Route length in miles :*	
(a) *single track*	...
(b) *double track.*	2.1
(c) *multiple track*	9.8
2. *Track voltage, frequency, etc.*	11 kV. single-phase 25-cy
3. (a) *Total power consumption (in kWh. × 10⁶) for last completed year, measured at generating station outgoing lines*	0.44 delivered to transmis lines at generating statio 11 kV. 3-ph. 25-cyc.
(b) *Voltage, etc., of generating station outgoing lines.*	6.95 delivered to transmis lines at metering point 22 kV. 1-ph. 25-cyc.
4. *Place where purchased energy (if any) is received*	All energy purchased, see 3 above.
5. *Load factor : I. Ratio between the maximum load over a period of 8 760 hours; II. Ratio of annual average load and the maximum load recorded over any period of 30 minutes during 8 760 hours :*	
(a) *at the point where the supply is taken*	Data not available.
(b) *at substations delivering :*	
1 *Up to 50 000 kWh. per week.*	...
2. *From 50 000 kWh. to 200 000 kWh. per week*	...
3. *From 200 000 kWh. to 500 000 kWh. per week.*	...
4. *More than 500 000 kWh. per week*	...
6. *System annual average power factor*	Data not available.
7. *Extent to which train timetables are drawn up with a view to improving the system load factor, or to using energy at times when there is a surplus of generating capacity.*	As far as possible, consi with existing traffic req ments.
B. Transmission lines.	
1. (a) *Distribution system (railway purposes only, or combined with an industrial network?)*	Railway only.
(b) *Voltage, frequency, etc.*	22 kV. 1-ph. 25-cyc. (earthed mid-point).
2. *Approximate route length of H.T. transmission lines :*	
(a) *used for railway purposes only*	11.9 miles (overhead)
(b) *used jointly with an industrial undertaking*	...
3. *For the last completed year of operation :*	
(a) *Max. load for traction purposes*	...
(b) *Max. load for other purposes*	See D.C. tables.
(c) *Energy consumption (kWh. × 10⁶) for traction purposes.* . . .	7.38
(d) *Energy consumption (kWh. × 10⁶) for other purposes*	See D.C. tables.

ent systems.

Pennsylvania.	Reading Co.	
38.5 139.9 195.0	... 67.2 16.5	
11 kV. single-phase 25-cyc.	12 kV. single-phase 25-cyc.	
35.92 measured at supply station busbars. ...	28.21 measured at receiving point. ...	
Supply substations.	Single point.	
	I 27.3 %.	II No records.
-55 % based on average load divided by load g demand periods, which are the average of high clock hour loads occurring on separate during each month.	No records of substation load factors.	
0.72 — 0.76 during demand periods.	0.8 — 0.9 during maximum load periods.	
No alterations to improve load factor.	Frequent service to encourage patronage.	
Railway only. 44 kV. and 132 kV. 1-ph. 25-cyc.	Railway only. 12-24-36 kV. 1-ph. 25-cyc. 3-wire.	
132 kV. — 665 circuit miles. 44 kV. — 85 circuit miles.	151 miles. ...	
143 600 kW. (1 hr.). ... 435.92 ...	11 900 kW. Approx. 50 kW. (signals). 27.77 0.44 (signals).	

—	Long Island.
4. *Measured or estimated annual loss in the H.T. transmission lines :* (a) *in kWh.* $\times 10^6$ . . . . (b) *as a percentage of the energy transmitted*	Estimated 0.11. Estimated 1.5 %.
5. *Max. voltage drop in the H.T. transmission lines under normal operation conditions.*	Approximately 9 %.
6. *Measures taken to reduce transmission losses :* (a) *by control of load division between generating stations operating in parallel.* (b) *by extension of the distribution system* . . . . (c) *by automatic voltage regulation at various points on the system.* (d) *by control of the division of wattless current between generating stations operating in parallel.* (e) *by the use of synchronous machines or static condensers* . . . (f) *by the insertion of reactors in the lines connecting generating stations.* (g) *by cutting out of service lightly loaded transformers or converters.* (h) *by any other means*	To the extent practicable. ... ... One synchronous condenser installed. ... Adopted. ...
7. *Steps taken to reduce discharge loss on insulators*	None.
8. *Steps taken to reduce corona loss*	None.
C. Traction substations. 1. *Number and type of substations in use*	1 — frequency changer. 4 — remote controlled auto transformer.
2. (a) *Equipment installed* . . . . (b) *Number and rating of sets*	1 — 5 000-kW. frequency changer. 50 % overload, 1 hr. 100 % overload, 5 mins. 5 — 3 000-kW. auto-transformers. 50 % overload 1 hr. 200 % overload 5 mins.
3. *Alteration in number of units in service in substations in order to improve substation efficiency.*	Changes made.
4. *Method of making and intervals between such changes*	Several times daily, locally and by remote control.

Pennsylvania.	Reading Co.
... Estimated 1.5 %.	1.69 } including transmission, contact line 6 % } and transformer losses.
l, on account of the high voltage and balanced load distribution between supply stations.	Approximately 8 % at contact line.
oad on generating stations restricted to that of surrounding territory. ... ... ıttless current supplied by generating stations restricted to needs of surrounding territory. synchronous condenser substation ; some genera-s in supply substations can be run light for P.F. rection. ... Adopted. ...	No special provisions ... ...
None.	None.
ıarge diameter hollow conductors and smooth surface attachments.	None.
7 — supply substations. 40 — step-down transformer. 1 — synchronous condenser. 8 — trolley switching. remote control except synchronous condenser.	11 — auto-transformer. 1 — three-winding transformer. All remote control.
Supply station transformers. 3 — 7 500 kVA. 10 — 15 000 kVA. 14 — 20 000 kVA. Step down transformers. 6 — 2 000 kVA. 8 — 3 000 kVA. 134 — 4 500 kVA. 4 — 5 000 kVA. 50 % overload 2 hrs. on all units. 4 500-kVA units 200 % overload 5 mins.)00-kVA and 20 000-kVA units. 150 % overload 5 mins.	2 — 4 000 kVA auto-transformers. 16 — 2 000 kVA auto-transformers. 3 — 8 000 kVA three-winding transf. 50 % overload, 2 hrs. and 200 % overload, 5 mins. without exceeding 60° C. temperature rise after reaching continuous load temperature.
Changes made.	Changes made.
t in service adjusted weekly by remote control.	Only one transformer in service in three winding transformer substation during night. Changes by remote control.

—	Long Island.
5. *Transformer efficiency at unit power factor and :* (a) *full load* . . . . (b) *half load*	 99.3 %. 99.3 %.
6. *Converter efficiency at unity power factor and :* (a) *full load* . . . . (b) *half load*	 88.1 %. 82.7 %.
7. *Replacement of motor alternator sets used to transform three-phase to single-phase current by single armature machines with a view to securing a higher efficiency.*	Single-armature machine unsuitable.
8. *Output voltage of phase and frequency converters (avoidance of step-up transformer with additional losses).*	Step up transformer used a converter substation.
9. *Use of mercury vapour converters to transform three- to single-phase current.*	None.
10. *Special measures taken and additional apparatus installed in substations to enable regenerative braking to be used.*	Not used.
D. **Contact system.**	
1. *Contact system used*	Overhead conductor.
2. *Total equivalent copper cross section of overhead line (square inches). and of feeder cables if any.*	0.26 sq. in. 45 % of total. 0.13 sq. in. 55 % of total. No parallel conductors.
3. *Paralleling of conductors between substations on multi-track lines to reduce losses.*	Not adopted.
4. *Use of continuous contact line circuits between substations with a feed from each end, to reduce losses.*	Adopted.
5. *Steps taken to secure low resistance of running rail and earth return :* (a) *type of bonding adopted* . . . . (b) *bonding together of parallel tracks* . . . . (c) *additional parallel conductors.* . . . . (d) *use of earth plates*	 Pin type, with composite st and copper connection. At intervals of 5 280'. None. None.
6. *Estimated energy loss in track system as a percentage of the substation output.*	Less than 1.0 %.

Pennsylvania.	Reading Co.
... % ... % more recent step-down units.	8 000 kVA 4 000 kVA and 2 000 kVA. 99.05 % 98.8 % 99.0 % 98.5 %
...frequency converters are owned and operated by the supply authorities.	Not employed by railway.
None.	None.
...up transformers used in all converter stations.	...
None.	None.
Not used.	Not used.
Overhead conductor.	Overhead conductor.
0.26 sq. in.	0.26 sq. in. 42.5 % of total. 0.22 sq. in. 49.6 % of total. 0.11 sq. in. 7.9 % of total. No parallel conductors.
Not adopted.	Not adopted.
Adopted.	Adopted.
Pin type. ...ll tracks at 25 000' intervals, adjacent pairs at 12 500' intervals. 0.32 sq. in. feeder on several long sections. ...ot used to reduce earth return resistance.	Gas-welded bonds. At ends of alternate signal track circuits. 0.1 sq. in. earth wire carried on top of structure supporting posts is connected to alternate impedance bonds. None.
Estimated 1 %.	Less than 1 %.

—	Long Island.
E. Locomotives, motor cars and other rolling stock.	
1. *Steps taken in recent locomotive design to reduce current consumption :*	
(a) *methods of weight reduction*	Low-speed freight engine Drive on all axles.
(b) *motor speed at 1-hr. rating*	468 r.p.m.
(c) *coupling between motors and driving axles*	Gear.
(d) *gear ratio*	5.44 : 1.
(e) *fine regulation of starting current to enable better use to be made of adhesive weight.*	None.
(f) use of streamlining	None.
2. *Use of mercury vapour rectifiers carried on trains*	Considered, but no conclus[ion] reached, not tried out.
3. *Steps taken in recent motor coach and multiple unit train design to reduce current consumption :*	No motor coach stock.
(a) *methods of weight reduction*	...
(b) *motor speed (r.p.m.) at 1-hr. rating*	...
(c) *coupling between motors and driving axles*	...
(d) *gear ratio*	...
(e) *fine regulation of starting current to enable better use to be made of adhesive weight.*	...
(f) *use of streamlining*	...
4. *Use of roller bearings on motor armatures and on axles of locomotives and rolling stock.*	None on A.C. locomotives. D.C. tables for motor co[ach] stock.
5. *Electric train heating :*	
(a) *system (direct or electrically heated steam boiler)*	None on A.C. system.
(b) *reduction in peak demand by cutting out heating during acceleration.*	...
(c) *control of heating by train staff*	...
(d) *control of heating by automatic devices*	...
(e) *energy used for heating as a percentage of total used annually for all purposes on the railway.*	...
6. *Regenerative braking :*	
(a) *conditions in which it is employed*	Not used.
(b) *operation of regenerative brake in conjunction with other brakes.*	...
(c) *energy recovered by regenerative brake*	...
(d) *weight of additional apparatus required for regenerative braking, and increased motor rating necessitated.*	...
(e) *effect of the brake on the power factor*	...

Pennsylvania	Reading Co.
types of recent design P5a freight and passenger, GG1 express passenger. P5a riveted aluminium cabs. GG1 welded steel cabs. P5a : 1 250 r.p.m. at 90 m.p.h. GG1 : 1 910 r.p.m. Quill with spring cup. P5a 2.94 : 1. GG1 3.59 : 1. 1 has buck and boost transformer which treble number of notches. Streamlined, primarily for appearance.	No locomotives in use. ... ...
Not considered to be applicable.	None.
multiple trains, the introduction of trailer units d to reduction in total weight of electrical uipment. tor trailer units . . . 1 120 r.p.m. } at. cont. gle car units . . . . 890 r.p.m. } rating. Flexible gear. Motor trailer units: 2.59 : 1. Single car units: 2.21 : 1. Current-limiting relay. None.	Aluminium employed for panels, roof fittings, conduits, etc. 864 r.p.m. and 900 r.p.m. Flexible gear. 2.85 : 1 and 2.59 : 1. Current-limiting relays. None.
P5a and most GG1 axles, and motor bogies of otor trailer units and most single car units. n all armatures except some single car units nd on some passenger rolling stock axles.	On all motor armatures.
ct on multiple unit stock; elec. boiler on two locos.; others have oil-fired boilers. Not cut out. Semi-automatic. Thermostats on some cars. Approx.: 2 %.	Direct. Not cut out. When desired. By thermostats. Between 10 % and 30 % during winter months.
Not used.	Not used. ... ...

Direct-curren

—	Baltimore and Ohio.		Buenos Ayres Western.	Central Argentine	
A. General details of electrified lines.					
1. *Route length in miles :*					
(a) *single track*	3.7 route-miles.		4.85	...	
(b) *double track*	9.7 track-miles.		14.05	39.65	
(c) *multiple track*	...		9.0	2.85	
2. *Track voltage*	650 volts.		800 volts.	825 volts.	
3. (a) *Total power consumption (in kWh × 10^6) for last completed year.*	4.75 (purchased).		39.62 (purchased).	69.19 (generated).	
(b) *Voltage, etc. of generating station outgoing lines.*	...		20 kV. 3-ph. 50-cyc.	20 kV. 3-ph. 25-cy	
4. *Place where purchased energy (if any) is received*	Supply authorities substation.		Generating station	No power purchase	
5. *Load factor :* I. *Ratio between the maximum load and the average load over a period of 8 760 hours;* II. *Ratio of average load and the maximum load recorded over any period of 30 minutes during 8 760 hours :*	I	II		I	II
(a) *at the point where the supply is taken.*	28 %	No record.	Not available.	27.05 %	41.5 %
(b) *at substation delivering :*					
1. *Up to 50 000 kWh per week*	...		...	...	...
2. *From 50 000 kWh to 200 000 kWh per week.*	...		...	11.0 %	34.8 %
3. *From 200 000 kWh to 500 000 kWh per week.*	...		...	The figures correspondi to 2 vary considerab and an average h been struck betwe the manual substatio	
4. *More than 500 000 kWh per week.*	...		...	...	
6. *System annual average power factor*	Unity.		Not available.	0.96-0.98 lag.	
7. *Extent to which train timetables are drawn up with a view to improving the system load factor, or to using energy at times when there is a surplus of generating capacity.*	Not at all.		No avoidable running of freight trains during peak load periods.	Purely suburban se vice, little can done.	
B. Transmission lines.					
(a) *Distribution system (railway purposes only or combined with an industrial network?).*	Railway only.		Railway only (incl. supply to workshops of 2nd railway).	Railway only.	
(b) *Voltage, frequency, etc., of distribution system.*	13.2 kV. 3-ph. 25-cyc.		20 kV. 3-ph. 50-cyc.	20 kV. 3-ph. 25-cy	
2. *Approximate route length of H.T. transmission lines :*					
(a) *used for railway purposes only*	2 miles.		75 miles (cable).	104 miles.	
(b) *used jointly with an industrial undertaking.*	...		...	...	

tems.

Great Western Railway.		London Midland and Scottish Railway				
ammer-nith & City.	Ealing & Shepherds Bush.	London-Watford.	Bow-Upminster.	Liverpool-Southport.	Wirral Peninsula (under construction, all figures estimates).	Manchester-Bury.
...	...	4.5	...	...	...	...
4.65	4.2	35.75 incl. 2.25 joint ownership.	14.5 inc. 2 joint ownership.	33	10.5	3.5
...	...	...	...	4	...	10.5
600 volts.		630 volts.	630 volts.	600 volts.	650 volts.	1 200 volts.
9.62 (generated).		89.8 (generated).	33.76 (purchased).	40.76 (generated)	6.0 (to be purchased).	13.48 (purchased).
kV. 3-ph. 25-cyc.		11 kV. 3-ph. 25-cyc.	22 kV. 3-ph. 25-cyc.	7.5 kV. 3-ph. 25-cyc.	11 kV. 3-ph. 50-cyc.	11 kV. 3-ph. 50-cyc.
...		...	Supply authorities substation.	...	Supply authorities substation.	Supply authorities substation.
I	II	I II	I II	I II	I II	I II
...	50.7 %	3.0 40 %	... 32.2 %	3.2 40.5 %	... 25 %	... 32 %
Substation figures not recorded.		Substation load factors are not recorded.				
...		...	...	...	...	...
Unity.		Approx. unity.	Estimated 0.98-1.0 lag.	Approx. unity.	0.9-0.95 lag.	Estimated 0.9-0.95 lag.
...		All trafic is suburban, no attempt is made to improve load factor.				
Railway only.		Railway purposes only.				
kV. 3-ph. 25-cyc.		11 kV. 3-ph. 25-cyc.	11 kV. 3-ph. 50-cyc.	7.5 kV. 3-ph. 25-cyc.	11 kV. 3-ph. 50-cyc.	11 kV. 3-ph. 50-cyc.
single-circuit miles.		30 miles (cable).	12 miles (cable).	14 miles (cable). 14 miles (overhead .	12 miles (cable and overhead).	3.5 miles (cable). 5.5 miles (overhead).
...		...	...	...	...	...

—	Baltimore and Ohio.	Buenos Ayres Western.	Central Argentine.	Great Western Railwa[y]	
				Hammer-smith & City	Ealing & Shepherd[s] Bush.
B. Transmission lines (*contd.*).					
3. *For the last completed year of operation :*					
(a) *Max. load for traction purposes*	1 900-kW.	10 800-k×. (1 hr.)	30 200-kW. (peak).	5 520-kW. (30 min.).	
(b) *Max. load for other purposes.*	...	...	...	...	
(c) *Energy consumption (kWh. × 10⁶) for traction purposes.*	4.75	27.63 } excluding conversion losses.	61.16	11.42 } (excluding conve[r]sion losses).	
(d) *Energy consumption (kWh. × 10⁶) for other purposes.*	...	5.59 } excluding conversion losses.	...	7.76 } (excluding conve[r]sion losses).	
4. *Measured or estimated annual loss in the H.T. transmission lines :*					
(a) *in kWh. × 10⁶*	...	6.4 } including conversion losses.	3.36 (estimated).	0.45	
(b) *as a percentage of the energy transmitted.*	Approximately 2 %.	16.16 % } including conversion losses.	5 %.	2.3 %.	
5. *Max. voltage drop in the H.T. transmission lines under normal operating conditions.*	Negligible.	12 % at most remote substation.	10 %	Approximately 2.7 %.	
6. *Measures taken to reduce transmission losses :*					
(a) *by control of load division between generating stations operating in parallel* .	None.	None.	Only one generating station.	..	
(b) *by extensions of the distribution system.*	None.	None.	...	...	
(c) *by automatic voltage regulation at various points on the system. Situation of such points* .	None.	None.	...	...	
(d) *by control of the division of wattless current between generating stations operating in parallel*	None.	None.	...	...	
(e) *by the use of synchronous machines or static condensers. Situation of such devices.* .	Synchronous converters used in substations.	To a small extent.	...	Synchronous converte[rs] in all substations.	
(f) *by the insertion of reactors on the lines connecting generating stations*	None.	None.	...	...	
(g) *by cutting out of service lightly loaded transformers or converters*	Adopted.	Adopted.	When service conditions permit.	Adopted.	
(h) *by any other means*	None.	None.	...	...	
7. *Steps taken to reduce discharge loss on insulators*	None.	None.	No overhead line.	No overhead line.	
8. *Steps taken to reduce corona loss.* .	None.	None.	No overhead line.	No overhead line.	
C. Traction substations.					
1. *Number and type of substations in use.*	1 — manual control rotary converter.	4 — local control rotary converter.	5 — remote control, and 4 — manual control rotary converter.	3 — local control mot[or] converter.	
		Power and lighting supplies taken from transformer substa[tion] and M/G sets in one traction substation.			
2. *Equipment installed.* *Number and rating of sets.*	1—2 000-kW. unit. 3—1 000-kW. units. 25 % overload, 1 hr. 200 % overload momentarily.	11—1 000-kW.units. 50 % overload, 2 hrs. 200 % overload momentarily. 2—2 000-kW. units. 200 % overload momentarily.	9 — 1 000-kW. units. 15 — 2 000-kW. units. 200 % overload momentarily.	16 — 400-kW. units.	

London Midland and Scottish Railway.				
Euston-Watford.	Bow-Upminster.	Liverpool-Southport.	Wirral Peninsula (under construction, all figures estimates).	Manchester-Bury.
Approx. 25 500-kW. (30 min.).	11 960-kW. (30 min.). inc. loss in 22/11-kV. transf.	Approx 11 500-kW. (30 min.).	2 750-kW. (30 min.).	5 070-kW. (30 min.).
...	...	...	...	...
73.70	31.0	37.24	5.8	12.55
12.47	0.7	1.69	0.2	0.58
3.59 4 %.	1.01 3 %.	1.84 4.5 %.	0.15 2.5 %.	0.34 2.5 %.
6 %.	...	21 %.	...	13 %.
Single supply point only on all lines.				
None.				
None.				
See (*a*) above.				
The power factor of synchronous converters is adjusted approximately to unity.				
None.				
Adopted.				
None.				
None — maximum voltage used on overhead lines 11 kV.				
None.				
— local control rotary converter.	4 — rotary converter. 2 — rectifier. 1 — rotary and rectifier. 1 — local control and 6 — remote.	6 — local control rotary converter. 2 — remote control glass bulb rectifier. 1 — battery.	1 — manual and 5 — remote control single unit rectifier.	1 — local and 1 — remote control glass bulb rectifier.
9 — 1 500-kW. units. 25 % overload 2 hrs.)0 % overload 10 mins. % overload momentarily. 6 — 1 000-kW. units. 25 — 750-kW. units. 25 % overload 2 hrs. 50 % overload 10 mins. 100 % overload 1 min.	13 — 1 200-kW. rotaries. 5 — 1 200-kW. rectifiers. 25 % overload 1 hr. 100 % overload 10 min. 200 % overload 10 sec.	4 — 1 200-kW. rotaries. 2 — 1 200-kW. rotaries. 13 — 750-kW. rotaries. Old machines, various overloads. 2 — 1 200-kW. rectifiers. Overload as Bow-Upminster plant.	6 — 600-kW. units. 25 % overload 2 hrs. 200 % overload 10 secs	6 — 1 200-kW. units. Overloads as Bow-Upminster plant.

	Baltimore and Ohio.	Buenos Ayres Western.	Central Argentine.	Great Western. Hammer-smith and City.	Great Western. Ealing ar[d] Shepherd[s] Bush.
C. **Traction substations** (*contd.*).					
3. *Alteration in number of units in service in the substations in accordance with load requirements to improve the S/S efficiency.*	Changes made.	Changes made.	Changes made.	Changes made.	
4. *Method of making and intervals between such charges.*	Frequently, manually.	Locally, 6 times daily.	Remote or local control, 3 times daily.	Locally, 4 times dail[y]	
5. *Transformer efficiency at unity power factor and :*					
(a) *full load*	98.5 %	Included in 6 below.	Included in 6 below.	...	
(b) *half load*	98.0 %			...	
6. *Converter efficiency at unity power factor and :*		1 000-kW. un. / 2 000-kW. un.			
(a) *full load*	No tests.	94.0 %. / 94.03 %.	94.03 %.	91.5 %.	
(b) *half load*		91.65 %. / 93.23 %.	93.23 %.	89.0 %.	
7. *Replacement of motor generator sets used to transform three phase alternating current to direct current by single armature machines with a view to securing a higher efficiency.*	M/G sets never used.	None.	None.	None.	
8. *Replacement of rotary converters used to transform 3-phase to D.C. by mercury arc rectifiers.*	None.	None.	None.	None.	
9. *Mercury rectifiers :*					
(a) *Substation efficiency*	...	...	...	...	
(b) *Means taken to minimise auxiliary losses.*	...	...	...	...	
(c) *Fitting of heaters, either internal or external and minimum temperature at which the restifier can carry :* 1. *full load* . . . . 2. *momentary rated overload.* .	...	...	...	...	
(d) *Circumstances in which « backfires » have occurred.*	...	...	...	...	
(e) *Purposes for which grid control is used.*	...	...	...	...	
(f) *Power factor at (1) full load (2) momentary rated overload. Method of measurement*	...	...	...	...	
(g) *Difficulties experienced with either distortion of the primary wave form or with ripples in the output and how these have been overcome. Reasons for fitting output filter circuits.*	...	...	...	...	
10. *Special measures taken and additional apparatus installed in substations to enable regenerative braking to be used.*	Not used.	...	Not used.	Not used.	
D. **Contact system.**					
1. *Contact system used*	3rd rail.	3rd rail.	3rd rail, under-running type.	3rd and 4th rails.	3rd rai[l]
2. *Steps taken to secure low resistance of third rail :*					
(a) *by the use of special material* .	Standard material.	Special material.	High-conductivity steel.	Careful manufactu[re]	
(b) *by the use of special sections (size used).*	100 lb./yd. rail.	...	86 lb./yd. rail.	...	
(c) *by improved methods of bonding (type and size).*	Welded.	...	Pressed 2×0.166 sq. in.	Pin type.	

London Midland and Scottish Railway.				
Euston-Watford.	Bow-Upminster.	Liverpool Southport.	Wirral Peninsula (under construction, all figures estimates).	Manchester-Bury.
Changes made.				
Frequently to follow two peaks daily; see 2 above for method of operation.				
00-kW. 1 000-kW. 750-kW. 98.45 % 98.35 % 98.05 % 98.85 % 98.15 % 98.0 %	Rotaries, rectifier (latest). 98.6 % 98.35 % in 6 below.	Rectifiers incl. in 6 below.	... ...	Incl. in 6 below.
... 96.0 % 96.0 % ... 94.2 % 94.5 %	96.2 % 94.6 % 94.8 % 95.0 %	94.0 % 94.2 %	... ...	95.6 % 96.0 %
None.				
No replacement by rectifiers, but they are being used in all new work.				
Steel tank units. Automatic control of cooling fan. Internal on earlier units (1) and (2); 5° on latest unit.		Figures not available.	Glass bulb units. Automatic variable speed control of cooling fans. No heaters.	
Of rare occurrence, circumstances not established.				
Grid control not used.				
(1) 0.95. (2) ... Ratio of input kW. to kVA.			...	
No troubles on primary or on output side. Six-phase connection, 2 units have complete filters and 3, including latest, have series reactor only.			Twelve-phase connection, smoothing equipment not provided.	
Not used.				
3rd and 4th-rail	3rd and 4th-rail.	3rd-rail.	3rd-rail.	Side contact 3rd-rail.
The composition of the steel used is strictly controlled. 105-lb./yd. rail.	105-lb./yd. rail	105-lb./yd. rail.	105-lb./yd. rail.	85-lb./yd. rail.
Standard bond pressed type (1.4 sq. in.); tests of gas-welded type (0.8 sq. in.) in progress.				

—	Baltimore and Ohio.	Buenos Ayres Western	Central Argentin
D. Contact system (*contd.*).			
3. *Total equivalent copper cross section of overhead line (square inches) and of feeder cables if any.*	...	Overhead conductor in use only on a limited length of siding.	...
4. *Paralleling of conductors between substations on multi-track lines to reduce losses.*	Adopted.	...	...
5. *Continuous contact line circuits between substations with a feed from each end to reduce losses*	Single substation.	...	Adopted.
6. *Steps taken to secure low resistance of 4th rail.*	...	...	...
7. *Steps taken to secure low resistance of running rail and ground return :*			
(a) *type of bonding adopted and size*	Welded 2 × 0.2 sq. in.	Concealed pressed, pin type in small quantity.	Pressed 2 × 0.2 sq. in.
(b) *bonding together of parallel tracks*	Every 1 000'.	Every 330'.	Every 300' exce where track c cuits installed.
(c) *additional parallel conductors*	0.8 sq. in. feeder part of distance.	Additional uninsulated rail in some places.	None.
(d) *use of earth plates*	None.	None.	None.
8. *Estimated energy loss in track system as a percentage of the substation output.*	No data.	No figures available.	10 %.
E. Locomotives, motor cars and other rolling stock.			
1. *Steps taken in recent locomotive design to reduce current consumption :*			
(a) *methods of weight reduction*	8 — 120 ton locomotives. Field weakening.	None.	No locomotives
(b) *motor speed (r.p.m.) at 1-hour rating*	...	485 r.p.m.	...
(c) *coupling between motors and driving axles.*	Single reduction	Gear drive.	...
(d) *gear ratio*	4.36 : 1	3.89 : 1	...
(e) *fine regulation of starting current to enable better use to be made of adhesive weight.*	None.	None.	...
(f) *use of streamlining*	None.	None.	...
2. *Steps taken in recent motor coach and multiple-unit train design to reduce current consumption :*	No multiple-unit cars.		
(a) *methods of weight reduction*	...	None.	None.
(b) *motor speed (r.p.m.) at 1-hour rating*	...	745 r.p.m.	632 r.p.m. an 645 r.p.m.
(c) *coupling between motors and driving axles.*	...	Gear drive.	Unit drive.
(d) *gear ratio*	...	3.42 : 1	3.18 : 1 and 3.23
(e) *fine regulation of starting current to enable better use to be made of adhesive weight.*	...	Current limiting relays	Current limitin relays.
(f) *use of streamlining*	...	None.	None.

Great Western.		London Midland and Scottish Railway.				
ammer-smith City.	Ealing & Shepherds Bush.	Euston-Watford.	Bow-Upminster.	Liverpool-Southport.	Wirral Peninsula (under construction, all figures estimates).	Manchester-Bury.
...		...	...	...	...	...
ough switches to allow eparate working in nergency.		...	...	6 sets of paralleling breakers.	At terminals, through isolating switches.	Through isolating switches.
Adopted.		...	...	Adopted as standard arrangement.		...
eful manufacture (4th ail in use on one line nly).		As 2 above.	As 2 above.	...	...	...
Fin type.		...	...	Pressed type (0.3 sq. in.) has been used, but gas-welded type (0.16 sq. in.) adopted for new work.		
...		...	...	All rails and tracks every 1 320'.	All rails and tracks every 1 320'.	Rails every 330'. Tracks every 1 320'
× 0.75 sq. in. from ubst. to distant part f track.		...	...	None.	None.	Additional uninsulated rail in many places.
None.		...	...	None.	None.	None.
3.1 %	3.3 %	...	...	...	...	...
olling stock provided by L.P.T.B.		...	...	No locomotives in use.		...
...		...	...	...	...	...
...		...	...	...	...	...
...		...	...	...	...	...
...		...	...	...	...	...
...		...	...	...	...	...
		Stock provided by L.P.T.B.				
...		None.	...	None.	Unit body & underframe, extensive use of welding, aluminium fittings	Aluminium panels and fittings.
...		642 r.p.m. (full field). 822 r.p.m. (weak field).	...	663 r.p.m.	734 r.p.m. full field 1 064 r.p.m. weak field.	580 r.p.m.
...		Single reduction gear.	...	← Single reduction gear. →		
...		3.33 : 1	...	3.33 : 1	3.94 : 1	2.36 : 1
...		Current limiting relays.	← Current limiting relays. →			
...		None.	← None. →			

	Baltimore and Ohio.	Buenos Ayres Western.	Central Argentine.
E. Locomotives, motor cars and other rolling stock *(contd.)*.			
3. *Use of roller bearings on motor armatures and on axles of locomotives and rolling stock.*	None.	None.	...
4. *Electric train heating :*			
(a) *system (direct or electrically-heated steam boiler).*	None.	No electric heating.	No heating.
(b) *reduction in peak demand by cutting out heating during acceleration.*	...	...	...
(c) *control of heating by train staff . . .*	...	...	...
(d) *control of heating by automatic devices.*	...	...	...
(e) *energy used for heating as a percentage of total used annually for all purposes on the railway.*	...	...	...
5. *Regenerative braking :*			
(a) *conditions in which it is employed . .*	Not used.	Not used.	Not used.
(b) *operation of regenerative brake in conjunction with other brakes.*	...	...	...
(c) *energy recovered by regenerative brake.*	...	...	...
(d) *weight of additional apparatus required for regenerative braking, and increased motor rating necessitated.*	...	...	...

at Western (Gr. Br.)	London Midland and Scottish Railway.				
	London-Watford.	Bow-Upminster.	Liverpool-Southport.	Wirral Peninsula (under construction, all figures estimates).	Manchester-Bury.
...	87 % of armatures. 10 % of bogies.	...	None.	On all axles and armatures.	None.
...	Direct.	...	Direct.	Direct.	Direct.
...	Not adopted.	...	Not employed.	Not adopted.	Not employed.
...	According to instructions posted in stations.				
...	None.	...	None.	One thermostat per 3-car set.	None.
...	6 %	...	6 %	...	10 %.
Not used.	Not used.				
...	...				
...	...				
...	...				

(Continued overleaf.)

Direct-curr

—	London and North Eastern. Tyneside Lines.		Long Island.	
A. General details of electrified lines.				
1. *Route length in miles* .				
(a) *single track*	1.0		12.35	
(b) *double track*	28.25		97.8	
(c) *multiple track*	2.5		19.1	
2. *Track voltage*	600 volts.		650 volts	
3. (a) *Total power consumption (in kWh × 10^6) for last completed year.*	15.74 (purchased).		170.23 (purchased)	
(b) *Voltage, etc. of generating station outgoing lines.*	5.5 kV. 3-ph. 50-cyc.		11 and 33 kV. 3-ph. 25-cy 11 and 33 kV. 3-ph. 60-cy	
4. *Place where purchased energy (if any) is received*	Railway substations.		Generating station and ra way substations.	
5. *Load factor :* I. *Ratio between the maximum load and the average load over a period of 8 760 hours;* II. *Ratio of average load and the maximum load recorded over any period of 30 minutes during 8 760 hours :*	I	II	I. (5-min. demand)	II. (30-mi demand)
(a) *at the point where the supply is taken.*	2.7	37 %	25.2 %	26.3 %
(b) *at substation delivering :*				
1. *Up to 50 000 kWh per week*	...		13.8 % - 54.5 %	14.6 % - 58
2. *From 50 000 kWh to 200 000 kWh per week.*	...		17.4 % - 56.1 %	18.4 % - 59.
3. *From 200 000 kWh to 500 000 kWh per week.*	...		18.3 % - 26.2 %	19.5 % - 27.
4. *More than 500 000 kWh per week.*	...		...	...
6. *System annual average power factor*	...		25-cyc supply, 0.98 lag.	60-cyc. sup 0.92 lag.
7. *Extent to which train timetables are drawn up with a view to improving the system load factor, or to using energy at times when there is a surplus of generating capacity.*	Not at all.		Greatest extent possible, sistent with existing tra loadings.	
B. Transmission lines.				
(a) *Distribution system (railway purposes only or combined with an industrial network?)*	Combined.		Railway only.	
(b) *Voltage, frequency, etc., of distribution system.*	5.5 kV. 3-ph. 50-cyc.		11 kV. and 33 kV. 3-ph. 25-	
2. *Approximate route length of H.T. transmission lines :*				
(a) *used for railway purposes only*	...		21 miles cable, 83 mile overhead.	
(b) *used jointly with an industrial undertaking.*	Owned by supply authority.		...	

ems *(contd.)*

hern (Great Britain).	Staten Island Rapid Transit.		Bombay, Baroda and Central India.		Great Indian Peninsula.	
			Existing	Planned		
4.75	21.6		14.9	1.2	...	
			(sidings)		150	
422.2	...		14.15	16.0	33.25	
112.7	...		7.15	...		
660 volts.	650 volts.		1 500 volts.		1 500 volts.	
448 (purchased and generated). 11 kV. 3-ph. 25-cyc. l 33 kV. 3-ph. 50-cyc.	14.29 (purchased). 33 kV. 3-ph. 60-cyc.		30.32 (purchased). 22 kV. 3-ph. 50-cyc.		119.18 (purchased) 22 and 110 kV. 3-ph. 50-cyc.	
V. at an H.T. distribu- ng point. kV. at C.E.B. substa- ons.	Railway substations.		Supply authorities substation.		Two railway substations.	
	I	II			I	II
em momentary peak ad about 20 % above)-min. max. demand. ower factor of system 1 30-min. demand about) %. Substation load ctors not recorded but ary from about 45 % largest to 25 % at nallest.	28 %	No record.	Momentary loads not recorded. Power factor of system based on 15-min. demand 47.5 %.		...	46 %
	...	...			No record.	...
	...	...			No record.	...
	...	...			3.8	...
	...	...			None of this output	...
0.98-1.0 lag.	Unity.		Approximately 0.96 leading.		...	
quent service during ff peak hours.	Not at all.		Times of trains adjusted within 5-min. limit.		Services arranged to suit traffic requirements only.	
n H.T. transmission li- es owned by Central lectricity Board and sed for industrial pur- oses also. No details vailable.	Combined. 33 kV. 3-ph. 60-cyc.		Railway only. 22 kV. 3-ph. 50-cyc.		Railway only. 22 and 110 kV. 3-ph. 50-cyc.	
...	...		10 miles cable, 8.5 miles overhead.		271 single circuit miles 110 kV.	
...	30 miles.		...		33 single circuit miles 22 kV.	

—	London & North Eastern. Tyneside Lines.	Long Island.
B. **Transmission lines** (*contd.*).		
3. *For the last completed year of operation :*		
(a) *Max. load for traction purposes*	4 850-kW. (30 min.).	68 400-kW.
(b) *Max. load for other purposes*	15.74	1 600-kW.
(c) *Energy consumption (kWh. × 10⁶) for traction purposes.*	...	149.14
(d) *Energy consumption (kWh. × 10⁶) for other purposes.*	...	7.05
4. *Measured or estimated annual loss in the H.T. transmission lines :*		
(a) *in kWh. × 10⁶*	Not available.	5.46
(b) *as a percentage of the energy transmitted.*	...	3 1/2 %.
5. *Max. voltage drop in the H.T. transmission lines under normal operating conditions.*	...	13 % on 11 kV., 8 % on 33 k
6. *Measures taken to reduce transmission losses :*		
(a) *by control of load division between generating stations operating in parallel.*	...	To the extent practicable.
(b) *by extensions of the distribution system.*	...	...
(c) *by automatic voltage regulation at various points on the system. Situation of such points.*	...	None.
(d) *by control of the division of wattless current between generating stations operating in parallel.*	...	None.
(e) *by the use of synchronous machines or static condensers. Situation of such devices.*	...	Synchronous converters used some 25-cycle substations.
(f) *by the insertion of reactors on the lines connecting generating stations.*	...	None.
(g) *by cutting out of service lightly loaded transformers or converters.*	...	Adopted.
(h) *by any other means.*	...	None.
7. *Steps taken to reduce discharge loss on insulators*	...	None.
8. *Steps taken to reduce corona loss*	...	None.
C. **Traction substations.**		
1. *Number and type of substations in use*	5 — manual control and 2 — remote control rotary converter.	20 — manual control 25-c rotary converter (includ 4 transportable subst.). 1 — remote control 25-cyc. rotary converter. 9 — remote control 25-cyc. a 60-cyc. rectifier. 1 — manual control rotary c verter and rectifier.
2. *Equipment installed. Number and rating of sets.*	14 — 1 000-kW. units. 25 % overload 2 hrs.	70 — converter units of avera ratings. 1 775 kW. continuously. 57 1/2 % overload 2 hrs. 175 % overload momentaril

Southern (Gt. Br.).	Staten Island Rapid Transit.	Bombay, Baroda and Central India.	Great Indian Peninsula.
	5 856-kW.	7 683-kW. (15 min.).	20 000-kW. (inst.) at 110-kV.
	...	544-kW. (15 min.).	16 536-kW. (15 min.) at 22-kV. (a) and (b) not separately recorded.
	14.29	28.03	106.83
	...	2.29	12.34
	...	...	...
	Approximately 2 %.	...	9.6 % on 110-kV. No accurate records on 22 kV.
	Negligible.	4.5 %.	5.6 % on 110 kV.
	None.	None.	None.
	None.	None.	Use of duplicate feeders.
	None.	None.	None.
	None.	None.	None.
	Synchronous converters used in substations.	Synchronous converters used in substations.	None.
	None.	None.	None.
	Adopted.	Plant in service strictly limited.	Shut down as traffic permits.
	None.	None.	None.
	None.	None.	None.
	None.	None.	None.
— manual control rotary converter. — remote control rotary converter. — remote control rectifier.	1 — manual control and 5 — automatic control rotary converter.	3 — remote automatic control rotary converter. 1 — rectifier planned.	9 — local control, and 6 — remote control rotary converter.
–1 000-kW. rotary converters. 00 % overload 5 min.; 200 % verload 10 secs. –1 250-kW. rotary converters. 00 % overload 5 min.; 220 % verload momentarily. –1 875-kW. rotary converters. 0 % overload 15 min.; 265 % verload momentarily. –2 500-kW. rectifiers. 20 % verload 15 min.; 220 % overload momentarily.	13 — 1 000-kW. units.	8 — 2 500-kW. units. 25 % overload 1 hr.; 200 % overload momentarily. 2 — 2 000-kW. rectifiers planned. 50 % overload 15 min.; 200 % overload momentarily.	40 — 2 500-kW. units 3 000 amps. for 1 hr. 6 000 amps momentarily.

	London and North Eastern Tyneside lines.	Long Island.
C. **Traction substations** (*contd.*).		
3. *Alteration in number of units in service in the substations in accordance with load requirements to improve the S/S efficiency.*	Changes made.	Changes made.
4. *Method of making and intervals between such charges.*	Remote or manual control several times daily.	Manually, and by remote control several times daily.
5. *Transformer efficiency at unity power factor and :*		
(a) *full load*	98.5 %.	97 % approximate average.
(b) *half load*	98.8 %.	96 % » »
6. *Converter efficiency at unity power factor and :*		
(a) *full load*	94.9 %.	95 % approximate average.
(b) *half load*	92.9 %.	93.5 % » »
7. *Replacement of motor generator sets used to transform three phase alternating current to direct current by single armature machines with a view to securing a higher efficiency.*	None.	M/G sets never used.
8. *Replacement of rotary converters used to transform 3-phase to D.C. by mercury arc rectifiers.*	None.	None.
9. *Mercury rectifiers :*		
(a) *Substation efficiency*		Approximately 94 %.
(b) *Means taken to minimise auxiliary losses.* .		None.
(c) *Fitting of heaters, either internal or external and minimum temperature at which the rectifier can carry :*		
1. *full load.*		Internal, on 3 units only. (1) 15° C. (2) 25° C. Normal operating temperature 30° C. — 40° C.
2. *Momentary rated overload*		
(d) *Circumstances in which « backfires » have occured.*		Very infrequent occurrence; associated with partial loss of vacuum.
(e) *Purposes for which grid control is used* . .		Not used.
(f) *Power factor at (1) full load (2) momentary rated overload. Method of measurement.*		(1) 0.93. (2) ...
(g) *Difficulties experienced with either distortion of the primary wave form or with ripples in the output and how these have been overcome. Reasons for fitting output filter circuits.*		No trouble experienced.
10. *Special measures taken and additional apparatus installed in substations to enable regenerative braking to be used.*	Not used.	Not used.
D. **Contact system.**		
1. *Contact system used*	3rd rail.	3rd rail.
2. *Steps taken to secure low resistance of third rail :*		
(a) *by the use of special material*	Standard material.	Special composition.
(b) *by the use of special sections (size used).* .	120-lb./yd. rail.	...
(c) *by improved methods of bonding (type and size).*	Pressed.	Gas-welded.

Southern (Gr. Bt.).		Staten Island Rapid Transit.	Bombay, Baroda & Central India.	Great Indian Peninsula.
otary converters only; rectifiers are in single-unit substations (2 have spare units).		Changes made.	Changes made.	Changes made.
anually and by remote control to follow 2 daily peaks.		Frequently — manually and automatically.	By remote control at 4 predetermined times daily.	Locally and by remote control, frequently on main lines, twice daily on suburban lines.
otary converter 98.1 % 98.1 %	Rectifier included in 6 below.	98.5 98.0	Included in 6 below.	98.62 %. No record.
96.6 % 95.5 %	94.9 % 95.0 %	No tests.	93.5 %. 90.5 %.	93.93 %. 91.12 %.
None.		M/G. sets never used.	None.	None.
None.		None.	None.	None.
ubstation input not metered. utomatic control of recooler and vacuum pumps.		... ...	... ...	... ...
No heaters fitted; (1) and (2) 5° C.		...	...	...
uring track short-circuits and shortly after installation.		... ...	... ...	... ...
Not used. (1) 0.92. (2) 0.85.		... ...	... ...	... ...
ower factor = input kW./kVA rimary none; output none with efficient telephone circuit. Poor telephone circuits improved. No output filters used,		. .	...	...
...		Not used.	Not used.	Reverse power relay to operate series field short-circuiting device installed.
3rd rail.		3rd rail.	Overhead conductor.	Overhead conductor.
Special composition: low sulphur content.		Small copper content.	..	...
100-lb./yd. rail.		150-lb./yd. rail.	...	...
Pressed.		Improved, heat applied.	...	...

—	London & North Eastern Tyneside lines.	Long Island.
D. **Contact system** (*contd.*). 3. *Total equivalent copper cross section of overhead line (square inches) and of feeder cables if any.*	...	...
4. *Paralleling of conductors between substations on multi-track lines to reduce losses.*	Adopted.	Some automatic circu breakers installed.
5. *Continuous contact line circuits between substations with a feed from each end to reduce losses*	Adopted.	Adopted, in general
6. *Steps taken to secure low resistance of 4th rail.*	...	...
7. *Steps taken to secure low resistance of running rail and ground return :*		
(a) *type of bonding adopted and size*	Concealed, pressed.	Brazed to rail head
(b) *bonding together of parallel tracks*	All rails and tracks every 300' through 0.2 sq. in. bond.	Every 5 280'.
(c) *additional parallel conductors*	Additional uninsulated rail where one running rail used for track circuits.	Guard rails bonded a connected to track.
(d) *use of earth plates*	None.	None.
8. *Estimated energy loss in track system as a percentage of the substation output.*	10 %.	Approximately 1.5 %
E. **Locomotives, motor cars and other rolling stock.** 1. *Steps taken in recent locomotive design to reduce current consumption :*	No locomotives of recent design.	No locomotives of rec design on D.C. lines
(a) *methods of weight reduction*	...	...
(b) *motor speed (r.p.m.) at 1-hour rating* . . .	...	...
(c) *coupling between motors and driving axles.*	...	...
(d) *gear ratio*	...	...
(e) *fine regulation of starting current to enable better use to be made of adhesive weight.*	...	...
(f) *use of streamlining*	...	...
2. *Steps taken in recent motor coach and multiple-unit train design to reduce current consumption :*		
(a) *methods of weight reduction*	Stock under construction. Articulation. Combined welded underframes and bodies.	Experimental all - alu nium double-decked on trial.
(b) *motor speed (r.p.m.) at 1-hour rating* . . .	830 r.p.m. (weak field).	510 r.p.m.
(c) *coupling between motors and driving axles.*	Single reduction gear.	Gear drive.
(d) *gear ratio*	3.94 : 1	2.08 : 1
(e) *fine regulation of starting current to enable better use to be made of adhesive weight.*	Current maintained ± 20 % of mean starting value.	No fine control.
(f) *use of streamlining*	None.	None.

Southern (Gt-Br.).	Staten Island Rapid Transit.	Bombay, Baroda & Central India.	Great Indian Peninsula.	
...	...	0.675 sq. in. — 33 %. 0.625 sq. in. — 67 %. No parallel conductors.	1.0 sq. in. — 48 %. 0.625 sq. in. — 27 % 0.25 and 0.30 sq. in. — 25 %. No parallel conductors.	
...lway between some sub-...tations through high-...peed circuit breakers.	Adopted.	Automatic circuit breakers midway between substations.	Adopted.	
Adopted.	Adopted.	Adopted.	Adopted.	
...	...	...	...	
...ncealed, pressed: two per ...oint; welding under in-...vestigation.	Welded 2 × 0.2 sq. in.	Concealed, pressed.	Concealed, pressed.	
... either side of stations, ... at 150' intervals, 5 at ...500' intervals, then every ...00 ft.; in track-circuited ...areas every 1 300' through ...mpedance bonds (where ...necessary).	Every 1 000'.	Every 600'.	Every 150'.	
...ort lengths of additional ... rail in some areas.	None.	None.	None.	
None.	None.	None.	None.	
Not available.	No data.	Not available.	Not available.	
No locomotives.	No locomotives.	No locomotives.	Passenger:	Freight:
...	...	...	None.	None.
...	...	...	604 r.p.m.	537 r.p.m.
...	...	...	Gear drive	Jack shaft and connecting rods.
...	...	...	3.66 : 1	4.15 : 1
...	...	...	...	...
...	...	...	Partial.	...
None.	Light material.	Constructional methods.	...	
Fast stock 650 r.p.m. ...uburban stock 610 r.p.m.	...	720 r.p.m.	660 r.p.m.	
Single reduction straight gear.	Single reduction gear.	Single reduction gear.	Single reduction gear.	
Fast stock 2.48 : 1 Suburban stock 2.81 : 1	2.95 : 1	3.28 : 1	3.57 : 1.	
No fine control.	Pneumatic camshaft control.	Current limiting relays.	No fine control.	
Leading ends rounded.	None.	In some degree.	None.	

	London and North Eastern.	Long Island.
E. Locomotives, motor cars and other rolling stock *(contd.).*		
3. *Use of roller bearings on motor armatures and on axles of locomotives and rolling stock.*	All armatures and some bogies on new stock.	On a limited number of bog
4. *Electric train heating :*		
(a) *system (direct or electrically-heated steam boiler).*	Direct.	Direct on multiple-unit ca
(b) *reduction in peak demand by cutting out heating during acceleration.*	Not used.	Not used.
(c) *control of heating by train staff . . .*	Under staff control.	Under staff control.
(d) *control of heating by automatic devices.*	Thermostats on new stock.	Thermostats on a limited nu ber of cars.
(e) *energy used for heating as a percentage of total used annually for all purposes on the railway.*	5 %.	Approximately 10 %.
5. *Regenerative braking :*		
(a) *conditions in which it is employed . .*	Not used.	Not used.
(b) *operation of regenerative brake in conjunction with other brakes.*	...	...
(c) *energy recovered by regenerative brake.*	...	...
(d) *weight of additional apparatus required for regenerative braking, and increased motor rating necessitated.*	...	...

Southern (Great Britain).	Staten Island Rapid Transit.	Bombay, Baroda & Central India.
None.	None.	None.
Direct. Not used. According to instructions posted in stations. avatory water heaters thermostatically controlled. 4 %	Direct 27 kw. per car. Cut out during acceleration. Manual control 50 % or 100 %. Thermostats fitted. ...	No electric heating. ... ...
Not used.	Not used.	Not used. ... ...

(Continued overleaf.)

Direct-curre

—	Japanese Government (5 independent lines).		London Midland and Scottish and London a North Eastern Railwa Manchester - Altrincha
A. General details of electrified lines.			
1. *Route length in miles :*			
(a) *single track*	21.6	119	...
(b) *double track*	...	158.2	5.75
(c) *multiple track*	...	62	3.0
2. *Track voltage*	600 volts.	1 500 volts	1 500 volts.
3. (a) *Total power consumption (in kWh × 10⁶) for last completed year.*	372.7 (purchased and generated).		12.6 (purchased).
(b) *Voltage, etc. of generating station outgoing lines.*	11 kV. and 66 kV. 3-ph. 50-cyc.		11 kV. 3-ph. 50-cyc.
4. *Place where purchased energy (if any) is received*	Railway substations.		Supply authorities substation.
5. *Load factor :*			
I. *Ratio between the maximum load and the average load over a period of 8 760 hours;*			I: ... II: 26 %
II. *Ratio of average load and the maximum load recorded over any period of 30 minutes during 8 760 hours :*			
(a) *at the point where the supply is taken.*	56 % and 37 % at 2 interconnnected generating stations based on 30-min. load.		
(b) *at substation delivering :*			Substation load facto are not recorded.
1. *Up to 50 000 kWh per week* . . .	34.2 %	average values based on 1-hr. load.	
2. *From 50 000 kWh to 200 000 kWh per week.*	39.2 %		
3. *From 200 000 kWh to 500 000 kWh per week.*	40.0 %		
4. *More than 500 000 kWh per week.* .	...	...	
6. *System annual average power factor*	0.96-0.99 lag.		Estimated 0.98-1.0 la
7. *Extent to which train timetables are drawn up with a view to improving the system load factor, or to using energy at times when there is a surplus of generating capacity.*	...		None.
B. Transmission lines.			
(a) *Distribution system (railway purposes only or combined with an industrial network?)*	Railway only.		Railway only.
(b) *Voltage, frequency, etc., of distribution system.*	11 kV., 22 kV. and 66 kV., 3-ph. 50-cyc. 154 kV. under construction.		11 kV. 3-ph. 50-cyc
2. *Approximate route length of H.T. transmission lines :*			
(a) *used for railway purposes only*	18 miles 11 kV. cable 62 miles 22 kV. cable. 18 miles 22-kV. overhead. 180 miles 66 kV. overhead.		5.3 miles cable.
(b) *used jointly with an industrial undertaking.*	124 miles 154 kV. overhead.		...

tems *(Continued).*

New Zealand Government.		South Indian Railway.	South African Railways and Harbours.	
Otira hur's Pass.	Christchurch-Lyttleton.		Cape electrification.	Natal electrification and Reef under construction.
11.25 3.5 oute miles under construction.		... 18 ...	13.5 26 2.5	267 3 113 59 under construction. ... 16
1 500 volts		1 500 volts.	1 500 volts.	3 000 volts.
1.86 generated) 500 v. D.C.	2.31 (purchased) 11 kV. 3-ph. 50-cyc.	5.63 (purchased) 5.0 kV., 3-ph. 50-cyc.	Energy purchased. 12 and 33 kV. 3-ph. 50-cyc.	88 kV. 3-ph. 50-cyc.
...	Supply authorities substation.	Railway substation.	Metered as A.C., delivered at track feeders.	
		I: Maximum peak loads not recorded. II: 31.4 %, will be improved to 47 % by rearrangement of race traffic.	I: ... II: approx. 40 %	I: ... II: approx. 55 %
	... ...	Substation load factors not available.	Figures not available.	
...	Unity.	Maximum demand charges based on a agreed value of 0.95.	Estimated 0.95-0.99 lag.	
...	...	Careful co-operation with Traffic Dept. Movement of goods trains continuously regulated.	Arranged to suit traffic.	
No ransmission lines. ...	Railway only. 11 kV. 3-ph. 50-cyc.	Railway only 12 kV. and 33 kV. 3-ph. 50-cyc.	Combined. 12 kV. and 33 kV. 3-ph. 50-cyc.	88 kV. 3-ph. 50-cyc. (Natal). 10 kV., 20 kV., 40 kV. 3-ph. 51-cyc. (Reef).
... ...	5.7 miles ...	9 miles 33 kV. double circuit overhead for traction. 21 miles 5 kV. overhead and 3 miles 5 kV. cable for auxiliary supplies. ...	... 30 miles.	... 480 miles.

—	Japanese Government.	London Midland et Scottish and London North Eastern.
B. — Transmission lines (*contd.*).		
3. *For the last completed year of operation :*		
(a) *Max. load for traction purposes*	Tokyo and vicinity only. 65 000-kW. (30 min.).	5 540-kW. (30 min.).
(b) *Max. load for other purposes*	Tokyo and vicinity only. 6 000-kW. (30 min.).	
(c) *Energy consumption (kWh. × 10⁶) for traction purposes.*	271.9	12.47
(d) *Energy consumption (kWh. × 10⁶) for other purposes.*	38.7	0.93
4. *Measured or estimated annual loss in the H.T. transmission lines :*		
(a) *in kWh. × 10⁶*	...	0.6 approximately.
(b) *as a percentage of the energy transmitted.*	Approximately 5 %.	0.5 % approximately.
5. *Max. voltage drop in the H.T. transmission lines under normal operating conditions.*	3 % on 66-kW. line of 70 miles.	2 %.
6. *Measures taken to reduce transmission losses :*		
(a) *by control of load division between generating stations operating in parallel.*	None.	Single supply point.
(b) *by extensions of the distribution system.* .	None.	None.
(c) *by automatic voltage regulation at various points on the system. Situation of such points.*	None.	None.
(d) *by control of the division of wattless current between generating stations operating in parallel.*	None.	See (*a*) above.
(e) *by the use of synchronous machines or static condensers. Situation of such devices*	Synchronous converters used in many substations.	Rotary converter power factor adjusted approximately to unity.
(f) *by the insertion of reactors on the lines connecting generating stations.*	Synchronous condensers under installation on new 154-kV. line.	None.
(g) *by cutting out of service lightly loaded transformers or converters.*	Adopted.	Adopted.
(h) *by any other means.*	...	None.
7. *Steps taken to reduce discharge loss on insulators*	None.	No overhead lines.
8. *Steps taken to reduce corona loss*	None.	...
C. Traction substations.		
1. *Number and type of substations in use*	37 — 1 500-V. local control and 2 — 600-V. local control.	1 — manual control recti[fier] and rotary conver[ter]. 1 — remote control rotar[y] converter.
2. *Equipment installed.* *Number and rating of sets.*	110 — rotary converters mostly 2 000-kW.; or 50 % overload 2 hrs, 200 % overload 1 min. 8 — motor converters 2 000-kW.; 50 % overload 2 hrs; 100 % overload 5 min. 8 — rectifiers, mostly 2 000-kW.; 50 % overload 2 hrs; 200 % overload 1 min. 2 — motor generators 2 000-kW.; 50 % overload 2 hrs; 100 % overload 5 min.	5 — 1 500-kW. rotary co[n]verter sets of t[wo] 750-kW. units in seri[es]. 1 — 1 500-kW. rectifier[s] 25 % overload 1 hr. 100 % overload 10 mi[n]. 200 % overload 10 sec[.]

Zealand Government.		South Indian.	South African Railways. Cape electrification.	South African Railways. Natal electrification and Reef under construction.
...	960 kW	1 900-kW. will be reduced to 1 225-kW. by re-arrangement of race traffic.	...	...
...	...	135-kW.	...	...
86 D.C.	2.31 A.C.	4.64	47.3	126.96
(A.C. rate rators)	...	0.99	...	...
...		0.042	...	7.56
t paid for by Railway Dept.		1.5 %.	...	4.7 %.
...	Negligible.	Not recorded.	Not measured.	
...		None.	...	...
...		None.	...	...
...		None.	...	...
...		None.	...	...
...		None.	...	Automatic power factor control of converter set motors.
...		None.	...	...
...		Adopted.	...	...
...		None.	...	...
Oversize insulators.		Routine cleaning.	...	...
...		None.	...	Conductor size (7/.152) and flat spacing of 150". Adequate for voltage.
substations. One remote tomatic control rotary nverter.		2 — automatic and/or remote control rectifier.	6 — remote control rotary converter.	13 — remote control synchronous M/G set. 14 — local control rectifier-inverter 12 — remote control rectifier under construction for Reef line.
2 — 1 350-kW. units.		4 — 750-kW. units. 50 % overload 2 hrs. 70 % overload 5 min. 200 % overload 1 min. 340 % overload momentarily.	1, 2 or 3 units per substation. 2 000-kW. per unit. 200 % overload momentarily.	1 or 2 — 2 000 kW. M/G sets per substation. 50 % overload 30 min.; 245 % overload momentarily. 1 or 2 rectifiers per substation. Main line 1 667-kW. Branch line 1 500-kW. : 30 min. overloads 110 % and 65 %; momentary overloads 260 % and 265 %. Reef. 1, 2 or 3 1 500-kW. units per substation. 50 % overload 30 min.; 250 % overload 10 secs.

	Japanese Government.	London Midland & Scotti and London North Easter	
C. **Traction substations** (*contd.*).			
3. *Alteration in number of units in service in the substations in accordance with load requirements to improve the S/S efficiency.*	Changes made.	Changes made.	
4. *Method of making and intervals between such charges.*	Locally, twice daily.	Manually, or by remote co trol to follow two pea daily.	
5. *Transformer efficiency at unity power factor and :*	Rotary converters.	Rotaries	
(a) *full load*	98.6 %.	...	Rectifier, included in 6 belov
(b) *half load*	98.5 %.	...	
6. *Converter efficiency at unity power factor and :*	Rotary converters.		
(a) *full load*	96.1 %.	95.65 %	96.1 %
(b) *half load*	94.0 %.	93.05 %	96.2 %
7. *Replacement of motor generator sets used to transform three phase alternating current to direct current by single armature machines with a view to securing a higher efficiency.*	None, although efficiency of such plant is about 10 % below that of rotaries.	None.	
8. *Replacement of rotary converters used to transform 3-phase to D.C. by mercury arc rectifiers.*	None.	See note on L.M.S. 3rd-r systems.	
9. *Mercury rectifiers :*			
(a) *Substation efficiency*	92 % — 94 %.	...	
(b) *Means taken to minimise auxiliary losses.* . .	None.	...	
(c) *Fitting of heaters, either internal or external and minimum temperature at which the rectifier can carry :* 1. *full load.* . . . . 2. *Momentary rated overload*	Water heaters in one substation. Cooling water is kept above 10° C.	Internal heaters fitted ; rec fier not operated at l temperatures.	
(d) *Circumstances in which « backfires » have occured.*	During operation under heavy loads, at low temperatures and when in parallel with rotary converters.	During tests to determir limits of plant capacity.	
(e) *Purposes for which grid control is used* . .	Not used.	...	
(f) *Power factor at (1) full load (2) momentary rated overload. Method of measurement.*	(1) 0.93 — 0.948. (2) ...	(1) 0.95. (2) ...	
(g) *Difficulties experienced with either distortion of the primary wave form or with ripples in the output and how these have been overcome. Reasons for fitting output filter circuits.*	No difficulties, output filters used.	No difficulties, output filt used.	
10. *Special measures taken and additional apparatus installed in substations to enable regenerative braking to be used.*	Reverse power meters and reverse current high speed circuit breakers installed.	Not used.	
D. **Contact system.**			
1. *Contact system used*	Overhead conductor—1 500 v. Overhead conductor and 3rd rail — 600 v.	Overhead conductor.	
2. *Steps taken to secure low resistance of third rail :*			
(a) *by the use of special material*	...	...	
(b) *by the use of special sections (size used).* .	88-lb./yd. rail.	...	
(c) *by improved methods of bonding (type and size).*	Ribbon bonds.	...	

...w Zealand Government.	South Indian.	South African Railways.				
		Cape electrification.		Natal electrification and Reef under construction.		
Changes made.	Changes made.	Changes made to some extent.				
...y remote or automatic control.	By remote control, normally twice daily.	Locally, and by remote control.				
		Rotary converter included in 6 below.	M/G set.	2 000-kW. rect.	1 500-kW. rect.	1 500-kW. rect.
98.67 %.	98.34 % } 5/33-kV. transformer.		98.3	...	...	...
98.58 %.	98.50 %		...	...	...	...
				Main line.	Branch line.	Reef.
96.0 %.	95.2 % } including transformer and auxiliary losses.	94.7	91.2	99 %	99.3 %	99 %
...	94.4 %	93.2	88.1	99 %	99.3 %	99 %
None.	None.	None.				
None.	None.	None.				
...	94 % (full load).	Main line 96.79 %, branch line 96.0 %. Reef 97.25 % at full load.				
...tifiers will be used on ...e line under construc...on.	None.	None.				
...	None used.	No heaters.				
		(1) Early units 15° C.; new units 8° C. — 10° C. (2) ...				
...	None experienced during 4 years' operation.	None experienced, some internal short circuits due to failure of timing of grid impulse equipment.				
...	Not used.	Inversion and regulation of D.C. voltage on Natal units. Current suppression and backfire on all units.				
...	(1) 0.95. (2) Cannot be accurately measured.	(1) 0.91 Natal, 0.94 Reef. (2) No test figures. Watt component of primary current divided by total current.				
...	Interference with Government communication circuits; output filters fitted after 4 years' service and have proved satisfactory.	Output filters fitted, telephone interference overcome, but radio interference not eliminated.				
Not used.	Not used.	M/G sets designed for forward and reverse working. Rectifier sets consist of one forward and one inverter unit. No regenerative braking on Cape & Reef lines.				
Overhead conductor.	Overhead conductor (negative).	Overhead conductor.				
...	...	...				
...	...	...				
...	..	...				

—	Japanese Government.	London Midland & Scottish and London and North Eastern.
D. **Contact system** (*contd.*).		
3. *Total equivalent copper cross section of overhead line (square inches) and of feeder cables if any.*	2.8— 1.9 sq. in. 4 %, 1.8— 1.7 sq. in. 16 %, 1.4— 1.3 sq. in. 73 %, 1.2—.675 sq. in. 7 % } excluding short length at 600 v.	0.85 sq. in. 0.4 sq. in. in sidings.
4. *Paralleling of conductors between substations on multi-track lines to reduce losses.*	Not connected between substations.	None.
5. *Continuous contact line circuits between substations with a feed from each end to reduce losses*	Adopted.	Adopted.
6. *Steps taken to secure low resistance of 4th rail.*	...	...
7. *Steps taken to secure low resistance of running rail and ground return :*		
(a) *type of bonding adopted and size*	Pressed.	Pressed, but gas-welded for new work.
(b) *bonding together of parallel tracks*	Every 10 000'.	Every 1 320'.
(c) *additional parallel conductors*	0.5 sq. in. negative feeders on three short lengths on 1 500 v. On 3rd rail negative feeders of 2.5 sq. in.	None.
(d) *use of earth plates*	None.	None.
8. *Estimated energy loss in track system as a percentage of the substation output.*	Approximately 2 %.	...
E. **Locomotives, motor cars and other rolling stock.**		
1. *Steps taken in recent locomotive design to reduce current consumption :*		
(a) *methods of weight reduction*	Many parts are welded.	...
(b) *motor speed (r.p.m.) at 1-hour rating*	600 — 800 r.p.m.	...
(c) *coupling between motors and driving axles.*	Gear drive and some rod drive.	...
(d) *gear ratio*	Passenger 2.63 — 3.45 : 1. Freight 3.41 — 4.77 : 1.	...
(e) *fine regulation of starting current to enable better use to be made of adhesive weight.*	None.	...
(f) *use of streamlining*	On some express passenger locos.	...
2. *Steps taken in recent motor coach and multiple-unit train design to reduce current consumption :*		
(a) *methods of weight reduction*	Many parts are welded.	None.
(b) *motor speed (r.p.m.) at 1-hour rating*	600 — 800 r.p.m.	670 r.p.m.
(c) *coupling between motors and driving axles.*	Single reduction gear.	Single reduction gear
(d) *gear ratio*	2.04 — 2.52 : 1.	3.33 : 1
(e) *fine regulation of starting current to enable better use to be made of adhesive weight.*	Current limiting relays.	Current limiting relays
(f) *use of streamlining*	Under consideration.	None.

ew Zealand Government.		South Indian.	South African Railways.	
			Cape electrification.	Natal electrification and Reef under construction.
.7 sq. in. hroughout th 1.0 sq. in. eeder for 78 % of mileage.	0.75 sq. in. 23 %. 0.5 sq. in. 77 %.	0.45 sq. in. 0.11 sq. in. steel plus 0.15 copper in sidings.	Cape and Reef lines 0.4 sq. in. Natal 1.25 sq. in. 9 % (*). 1.0 sq. in. 14 % (*). 0.625 sq. in. 36 %. 0.4 and 0.5 sq. in. 41 %. (*) Including feeders.	
Adopted.		3 high-speed circuit breaker cabins; at terminals and in centre of line.	Adopted.	
Adopted.		Adopted.	Adopted.	
...		...	...	
Pressed.	Gas-welded.	Concealed, pressed.	Gas welded.	
Every 1 320'.		At average distance of 3 300'	Every 330'.	
q. in. negat- e feeder for 78 % of mileage.	No additional conductors.	None.	...	
None.		None.	...	
...		1.5 %.	Estimated 7 %.	
(Locomotives under construction).		None necessary.	...	None.
689 r.p.m. (full field). 933 r.p.m. (weak field).		650 r.p.m. (full field). 787 r.p.m. (weak field).	...	660 r.p.m. at 1 350 v.
Quill and spring cup.		Unit drive.	...	Single spur gear.
3.74 : 1.		4.94 : 1.	...	4.41 : 1
one—ratio of peak to mean starting current 1.09.		None.	...	None.
Within limits imposed by maximum dimensions, etc.		None.	...	None.
Design of stock under consideration.		Reduction of steel sections, aluminium alloy fittings, special materials, welding of underframes and bogies. Use of articulation.	None.	...
...		838 r.p.m.	592 r.p.m. at 700 v. per motor.	...
ingle reduction spur gear, flexible gear wheels.		Unit drive.	Single spur gear.	...
...		4.33 : 1.	3.13 : 1 (Cape).	3.58 : 1 (Reef).
No fine control.		Current limiting relays.	Current limiting relays.	...
None.		None.	None.	...

	Great Indian Peninsula.	Japanese Governm
E. Locomotives, motor cars and other rolling stock *(contd.).*		
3. *Use of roller bearings on motor armatures and on axles of locomotives and rolling stock.*	On a small number of motor coaches, more being fitted.	None.
4. *Electric train heating :*		
(a) *system (direct or electrically-heated steam boiler).*	No electric heating.	Direct on multiple-unit and a few local tra
(b) *reduction in peak demand by cutting out heating during acceleration.*	...	Under consideratio
(c) *control of heating by train staff . . .*	...	Not controlled by st
(d) *control of heating by automatic devices.*	...	No devices.
(e) *energy used for heating as a percentage of total used annually for all purposes on the railway.*	...	2 % (Tokyo Distri
5. *Regenerative braking :*		
(a) *conditions in which it is employed . .*	On freight locomotives, gradients of 1.0 %-2.7 %.	Recently introduced on les of mountain line, ient 2 1/2 %.
(b) *operation of regenerative brake in conjunction with other brakes.*	Used alone.	With air and hand br
(c) *energy recovered by regenerative brake.*	50 %-55 % of available train energy recovered.	Measured at loco. about of energy used.
(d) *weight of additional apparatus required for regenerative braking, and increased motor rating necessitated.*	3 tons extra weight in control apparatus and axle generators.	1 ton.

...don Midland and ...ish and London and North Eastern.	New Zealand Government.	South Indian.	South African Railways. Cape and Natal.
...	All axles and armature shafts of new locomotives and multiple-unit stock.	On armature shafts of locos. and motor coaches.	...
Direct.	Oil fired boilers on new locomotives.	Not used.	Reef suburban stock : Direct from 3 000-v. supply.
Not used.	...	...	Not used.
...ntrolled by staff.	...	...	From driver's compartment.
No devices.	...	...	One thermostat in each motor coach.
8 %.	...	...	Not in service.
Not used.	Not used.	Not used.	Natal locomotives only, gradients of 0.4 % to 3.3 %.
...	...	...	Used alone.
...	...	...	6 % of substation input.
...	...	...	Equipment 2.75 tons; motors none as gradient is largely in one direction.

(The end.)

[656. 254]

INTERNATIONAL RAILWAY CONGRESS ASSOCIATION

13th SESSION (PARIS, 1937).

QUESTION IX.

Results obtained from the automatic and distant operation of signals and points, and from locomotive cab signals.

REPORT

(France and Colonies, Great Britain, Dominions and Colonies, Belgium and Colony, Luxemburg, America, China and Japan),

by J. TUJA,

Ingénieur en Chef de l'Exploitation, Paris-Lyon-Méditerannée Railways,

and A. LEMONNIER,

Chef de l'Exploitation, French State Railways.

CONTENTS :

This subject is extremely wide, as it has to study all modern types of signalling. In order to keep this report within reasonable bounds, we are confining ourselves to the examination of the principles of the subject, and to the study of the regulations, excluding all descriptions of appliances. Even so restricted, this report still touches on very many questions. We tender our thanks to the Railway Administrations, which have been good enough to reply so fully and so interestingly to the long questionnaire which we sent them.

This report is divided into three parts :

1. *Automatic block,* i. e., the automatic control of the signals to assure the spacing of trains running in the same direction on the same road.

2. *Power signal boxes,* i. e., signal boxes in which the points are operated — sometimes in certain modern installations at very great distances — electrically, hydraulically, pneumatically, etc.

3. *Locomotive cab signalling equipment* intended either to assist the driver, or in certain cases, to counteract any mistake he may make.

* * *

PART ONE.

Automatic block.

1. Signals used.

It is as well to note, in beginning this report, that automatic block signalling entails the use of two different types of stop signals.

Every railway requires a « stop » signal, which must not be run past under any circumstances, and which is utilised specially to protect the junctions. When the driver sees a signal of this type at *danger* he stops, and waits for the signal to be taken off.

A railway using the *manual block,* i. e., a block operated by the signalmen, can use as the manual block signal the type of stop signal which we have mentioned above to ensure the proper headway between the trains on the same line. The driver does not need to know why he finds the signal at *danger :* he stops and waits. In cases where the manual block regulations allow a train to enter a block section which is already occupied, the signalman notifies the driver, and authorises him to pass the signal at *danger*.

With automatic block the same procedure could be easily employed, that is to say, use for the block signal an absolute « stop » signal, if the equipment

never failed. Such an automatic block would be *absolute,* i. e. a driver finding a block signal at danger would await its coming off (or in rare cases a request for help brought by one of the staff of the train ahead, which has broken down within the block section); but, however perfect may be the construction and maintenance of automatic block equipment, it is impossible to ensure that a block signal will not sometimes remain at danger through some failure. Since there can be no question of stopping all train movements until the signal has been repaired, one is naturally led to making the automatic block into a *permissive* block, i. e., to authorise the train staff, under certain conditions which we shall study later, to pass on their own initiative *stop* signals which they find against them.

By installing close to each block signal a telephone connected to a station (or to the train dispatcher), it would always be possible for the automatic block to be treated as absolute, under the following regulation. A train could only run past a signal at *danger,* and not proceed at *caution,* on a telephonic order from the station which would only be given in the event of failure of the block equipment, *and after making sure that the section is free.* No railway system has standardised this method of signalling, which would have many drawbacks. It would necessarily lead to delays which, let us not forget, would not be without risk. It is difficult to draw up suitable regulations, for on certain busy sections, the stations might easily make a mistake and believe a section to be free which is actually occupied by a train, or by the rear part of a train, as for example, through the couplings breaking. Finally, it could not be applied easily in every case, for it might well happen that, should the telephone fail, the train staff themselves might decide to run past the signal at *danger,* or in other words to consider the block as permissive. That is why, in practice, one only finds this method of working at the entry to certain stations (see page 144/8) where freedom of the section ahead is easily verified, or in certain tunnels (see page 145/9) where there is danger in running at caution owing to bad visibility. Except in these particular instances, the automatic *permissive* block is in general use, so that *two* different types of stop signal are used, the one absolute, and used for example, to protect the junctions, and the other passable under certain conditions, always used in automatic permissive block signalling.

We find in fact both these different types of *stop* signals on all railways using the automatic block. Sometimes these two types of *stop* signal have quite different aspects; for instance, in France, where one finds the *square signal* (red and white chessboard, two red lamps at night and two red lights in daylight signalling) as absolute stop, as at junctions, and the *semaphore* horizontal arm, one red lamp at night, and one red light in daylight signalling) (*) as the block stop signal.

In other cases the aspects of the two types of *stop* signal are less different. Thus, on many American Railways the absolute stop signal is a horizontal arm having a square end shewing at night, or in daylight signalling, two red lights located one above the other, whilst the *stop and proceed* signal is a horizontal arm similar to the preceding one, but

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(*) The French Railways have just (1936) standardised their automatic block signalling of the daylight type in such wise that in future the aspect of the square signal and that of the semaphore will be less different. In the standardised signalling, the square signal, like the semaphore, shows a red light as visible as possible, but this red light is supplemented by a second light less visible than the first, and which can be either red or bluish white. If this auxiliary light is red, it represents a square signal and the *stop* is absolute, but if the auxiliary light is bluish white, it serves as a semaphore and the indication is *stop and proceed.*

pointed at the end, and shewing at night or in daylight signalling two red lights placed slightly obliquely one to the other.

In certain cases, only one type of « stop » signal, normally absolute, is used. Where this *stop* signal is used exclusively as the *stop and proceed* signal, a fixed marker sign is simply added, for example the letter A (automatic) which changes the signal into one of the second type and allows the driver to pass it under certain conditions. This method of working is met with particularly in Great Britain, where the *home* signal, a horizontal arm shewing one red light at night, is normally absolute, but may become a *stop and proceed* signal, if it is supplemented by the letter « A ». Actually, the British Railways have recently (1936) altered their installations materially. Instead of fitting the signals used exclusively for block working with the letter « A » (Automatic) they are now using the letter « P » (Proceed), having actually the same meaning, i. e., allowing the train staff to pass a signal at *danger* with caution, but, whilst the letter « A » is permanently exhibited, the letter « P » is normally extinguished, and illuminated by the neighbouring station, when this latter considers it safe to render the absolute *stop* passable, with caution, of course. In principle, the station only displays the letter « P » when the section is believed to be free. In other terms, under this new rule the automatic block is normally absolute, but is transformable into permissive at the will of a station, in principle only in the case of some breakdown. This system has been in use for too short a time to allow of any judgment thereon, but is there not some danger that, when used, drivers may become less attentive to the order for caution imposed by the signal at *danger*, caution all the more essential to safety if the section is really occupied? Since it would be difficult to ensure that a train *never* entered an occupied section, would it not be better to follow the example of nearly all the railways, and definitely introduce automatic *permissive* block working, carefully instructing drivers, of course, in the exact meaning of *proceed with caution* which we will study later.

In future we shall call the signal which trains may not run past under any conditions the *stop signal*, and the signal which may be passed under certain conditions the *stop and proceed* signal.

2. Passing block signals at danger.

When a driver runs past a *stop and proceed* signal at danger, he knows that he will not meet with any other obstacle than a preceding train running in the same direction on the same road (if it were otherwise he would be held up by the *stop signal* and not the *stop and proceed*) and safety will be assured if he takes precautions not to run into the rear of the train ahead, which may have been held up within the section. The driver, therefore, must be required to *run at caution*, which we will analyse later.

It might be envisaged that the *stop and proceed* signal does not oblige the driver to stop, but only to proceed with caution. In practice, with certain exceptions mentioned hereafter, all railways using the automatic block system require their drivers to come to rest in front of a block signal against him. We consider it would be wise to adhere to this principle of stopping, which most certainly causes the drivers to pay stricter attention to the indispensable condition of running through the section at caution. It may be noted here that the abolition of this obligation to stop would normally save very little time, seeing the block section is occupied by a train when a second train is offered. The saving in time would only become appreciable if the signal at the entry to a clear section remained at danger on ac-

count of a failure, and this is a rare occurrence.

Further, if a *stop and proceed* signal be passed without stopping, particularly if at a speed other than dead slow, there is more danger of the driver confusing the *stop* signal with the *stop and proceed* signal. Now, it must not be forgotten that the distinction between these two signals is fundamental to safety, and that it would be extremely dangerous to run, by mistake, past a *stop* signal at danger.

In fact, the only exception to the principle of stopping before a *stop and proceed signal* at danger is the following, which one meets with particularly on most of the American Railways. Certain signals, located on gradients which are difficult for goods trains, are labelled with the letter « G » (Grade). Passenger trains pay exactly the same attention to them as to the other *stop and proceed* signals, but goods trains are allowed to pass them, without stopping, at a speed not exceeding a fixed figure (15 miles per hour for example) and, of course, under the obligation to proceed cautiously within the section under the same conditions as after any other *stop and proceed* signal. This exception to the general rule does not appear to offer any drawbacks, and it is really valuable for the smooth working of the service, on account of the difficulty of restarting heavy goods trains on steep gradients. It might be extended with advantage to certain heavy passenger trains.

* * *

When a train is stopped before a *stop and proceed* signal, should it be allowed to be restarted *immediately* with the usual precautions, or only after a certain period has elapsed ?

On the railways consulted we find both these practices. Some railways prescribe a wait of several minutes. Many others, on the contrary, allow immediate departure after coming to a stop.

It would seem that this second procedure is the more logical. The object of waiting is evidently to give time for the section to be cleared whilst a train is waiting at the *stop and proceed* signal at danger. This train then leaves with the assurance that the section is clear, and is not expected to run at caution. If the block section is a long one, and if unfavourable atmospheric conditions impose a low speed on trains running with caution, this waiting might on occasion mean a definite gain in time. On the other hand, the delay to the train, if the *stop and proceed* signal remains at danger on account of failure of equipment is always, in fact, increased, As running at caution is sufficient to assure safety in every case, we agree with the majority of the lines consulted, that it is preferable not to prescribe any waiting time.

3. Running with caution.

The *stop and proceed* signal at *line clear* means that the road is clear up to the following signal, and the driver can run at speed, even if the length of clear line he can see is less than that required to stop.

When he passes a *stop and proceed* signal at danger, he has no longer this assurance, and must expect to find the road obstructed by the preceding train. He may, in fact, find it clear, for example, through some signalling failure, though he has usually no means of knowing if this is so. If on the other hand he does happen to know it, say, through talking with a linesman working on the signal, still be cannot be sure that the last train which passed, no matter how long before, has not broken down within the section. Consequently, it is imperative that a driver, passing a *stop and proceed* signal at danger, *shall expect to find the preceding train held up within the section*. In running

through this section he must act exactly like the driver of a motor car on the highway, where obstructions are not protected by signals, i. e., run « at sight »; in other words, he must so regulate his speed that at any moment he could stop in the length of road in sight under the actual condition of visibility. The proper speed varies, of course, from train to train, according to how the train is braked; it will vary also from one point to another on account of the gradients which may make a stop more or less difficult, and the location which may render visibility more or less good, etc... and it may vary from day to day according to atmospheric conditions, clear or foggy weather affecting visibility, and dry or wet rails, making stops more or less difficult...

Actually, all railways give their drivers instructions, which conform almost exactly to the method of running at sight described above.

Running at sight sometimes admits of fair speeds. In certain particularly favourable circumstances (a long straight stretch of road and fine clear weather) a driver might even attain a high speed, whilst still adhering rigidly to running at sight as above defined. Certain railways are not in favour of running at sight at high speed, and instruct their drivers, when running on sight not to exceed a definite speed, 15 m.p.h. on certain American roads, and even as low as 5 m.p.h. on certain English lines.

Such speed limitation combined with running on sight has some advantages. On the one hand it prevents running at sight at high speed, which we recognised as theoretically possible in certain cases, but introduces the risk of making some drivers somewhat careless. On the other hand it allows full profit to be taken of an indirect advantage of the automatic block system, which is that the signal at the entry to a section goes to danger if a rail breaks. Since such a fracture would be practically invisible, and running on sight would be of no avail in the circumstances, limitation of train speed over the broken rail is certainly desirable.

Against this, however, this limitation of speed has some disadvantages. Short of choosing an *extremely low speed* — and this becomes very annoying by the time which is uselessly lost in all cases when visibility is good or even average — the driver must keep to the limit fixed in the case of good visibility, and on the other hand, to a lower speed, according to circumstances when this limit is higher than running at sight warrants. This would somewhat complicate the regulations, and certain driver might confuse the fixed speed limit, 15 m.p.h. for instance, with the allowed speed admissible when running at sight, and eventually make the serious mistake of thinking that « running at sight » means running at 15 m.p.h.

Our definite opinion is that a restriction of speed in running at sight has more disadvantages than advantages, and that it is preferable not to prescribe it. We are supported in this view by the fact that the French Railways do not lay down any maximum speed and have not had any difficulty in practice. It is true that it is resorted to on other railways, equally without disadvantage, and it appears to be one of the questions — we shall meet with others — which belong not so much to the technical as to the psychological field, so it is no wonder that different solutions are acceptable, taking into account the outlook, traditions and habits of the personnel, which naturally vary much from one country to another, and at times even in the same country, or from one railway to the other.

* * *

Finally let us remember, at least in cases where the instructions for protecting trains standing at signals do not include hand signals (see paragraph 4) that running at sight only assures this

protection properly when the back of a train is clearly *visible* by the driver of the following train. By day this condition is normally possible, but at night the back of the train is only visible thanks to the lamps carried on all railways. It is clear that with the automatic block system the good visibility of these lamps is particularly desirable, and in our view this renders somewhat unwise the reduction of the number of tail lamps which has been sometimes proposed by certain Railways.

4. **Protection of stopped trains.**

When a train is stopped on a line equipped with automatic block signals, is it desirable to place entire confidence in the system, and to consider that the train staff need take no other steps to protect it ? Should not the staff be instructed to protect the train by means of hand signals ?

The regulations in force differ widely.

Certain railways place absolute confidence in the block system, and do not prescribe any protection measure by hand signals. This is the case, for instance, on the French Railways whose regulations are in agreement not to protect the train at a distance equal to the normal braking distance (say, approximately 1 000 m. = 3 280 ft.) safe in exceptional cases (almost all wheels of a train derailed or isolated vehicles left on the line through the couplings breaking, etc.).

Other railways prescribe protection of a train by hand signals in the case of an exceptional stop on the open road, under the same conditions as with manual block working. This is the case on the British Railways, and also in Japan, in the latter case at a distance of only 200 m. (656 ft.).

Finally, most of the American Railways rely a good deal on the initiative of their staff, only prescribing protection « at a sufficient distance to assure the safety of their train » when the train « is stopped under such circumstances that it can be caught up by another ».

Which of these rules is preferable ? Here again traditions must be taken into account, as also the different organisation of the various Railways. Thus, the American rule is entirely satisfactory to the railways using it, as their train staffs have plenty of initiative and often take on themselves grave responsibilities as regards safety of their train. It would certainly be less practicable in Europe, where usually the station staff has more to do with the safety of the trains than the train staff.

Train protection by hand signals can be looked at in two ways. It may be considered — always assuming that it is done at a long distance — as a means of ensuring safety when failure of apparatus necessitates keeping a signal at *clear* after the passage of a train (*). On the contrary, it might be regarded as an additional precaution, intended above all to assist a driver when entering an occupied section.

In both cases it seems to us that the employment of such protection carries with it the risk, at least on certain railways, of drawbacks of a psychological nature. Might it not be feared to some extent that certain drivers, who scrupulously respect « running at sight » conditions when entering an occupied section where they know they may meet with a train *not* protected by hand signals, may be a little less careful if they know that the train ahead ought to be protected ?

However — we will touch on this later — the working of automatic block apparatus appears to be remarkably re-

(*) It should be noted that, in this case, protection by hand signals would be effective only if the trains follow at intervals of at least ten minutes, but automatic block sections are usually so short that trains can run much closer together.

gular, particularly in the case of daylight signalling installations.

In a word, our opinion is that the best rule — and it is evidently the simplest, a quality which cannot be too highly estimated — is that which gives confidence in the automatic system, and does not prescribe any protection (*).

Of course all this is true only if the sections are not too long. The longer the section the greater is the probability of the driver disregarding the need for caution, and this probability increases very rapidly with the length of the section. It seems to us advisable to apply the rule which we have just discussed only in the case of sections the length of which does not exceed 3 km.

5. Particular case of stations.

We have just seen that, as a general rule, the entry to a block section should be protected by a *stop and proceed* signal. At the entry to stations and in the vicinity of junctions, the problem to be dealt with is, on the one hand, to prevent, exactly as on the open road, the collision of two trains running in the same direction, and on the other to avoid trains being run into when crossing the points.

The entry to these block sections can be protected by three methods :

a) *Two* signals can be placed side by side; a non-automatic *stop* signal, only used by the signalman to prevent collision on the station junction points, and an automatic *stop and proceed* signal, working exactly as on the open road.

b) A *stop* signal at the entry to the section, used by the signalman to protect the points, and automatically to protect standing trains or vehicles might meet the need, or

c) A *stop and proceed* signal, automatically protecting trains at rest as on the open road, and also used to protect the points. The signal in this latter case is placed at *stop* by moving a lever interlocked with the points; further, since this signal is permissive, the signalman completes the protection of the points by placing on the line at a suitable spot a manual *stop* signal, sufficient to stop any following train, which could only run at caution when past the main signal in the danger position.

(*) Except in certain special cases, such as a derailment, for instance.

Let us compare these three systems briefly.

a) The first (using a *stop* signal and a *stop and proceed* signal) is met with in all *automatic light signal installations*. Light signals are specially suitable for this system, which is undoubtedly less suitable for mechanical signalling. It would not be altogether satisfactory with mechanical signalling to have at the entry to a station a stop signal at clear alongside of a *stop and proceed* signal at danger while a train is standing in the station. This inconvenience disappears in light signalling, which only gives one indication at any given moment.

When this system is used, no staff is needed at a junction during the period of the day during which the trains are all running in the same direction. Further, it allows a station to be entirely closed, during the time no trains are using it.

b) The second system (employing a single *stop* signal) certainly offers the advantage of being simpler than the first named. On the other hand it has the disadvantage — except under particular precautions which complicates the working — of making it impossible to close a junction or a station during the period in which no point movements require to be made therein.

This system naturally is employed in Great Britain, where, as already stated,

only one type of *stop* signal is used, normally absolute, but rendered permissible at the entry to sections where it will not cause inconvenience, by a marker label « A » or « P ».

c) The third system (using a single signal, *stop and proceed* and therefore passable, supplemented by a manual *stop*, which is absolute when necessary) is as simple as the second, and offers the same facilities as the first for closing junctions or main-stations during certain periods. Against this, it has the disadvantage that a signalman can make the mistake of not setting the manual stop signal in order to complete the protection given by the *stop and proceed* signal; and it is advisable only to use it for the protection of small stations where movements are rare, and to use one of the two other systems at junctions, or at the entry to main stations.

Actually, all three systems are met with, but as we have just pointed out, it seems advisable to reserve the third system for small stations. The two first named, however, which should be used at important stations, appear to be equally satisfactory from the point of view of safety; and the choice between the two must depend principally upon the working conditions.

6. Particular case of tunnels.

Where a section has no points, but runs through a tunnel, the inside of the tunnel on heavy steam lines, may be so full of smoke and steam that the visibility becomes practically nil. This may call for special regulations for tunnels where it is impossible to get adequate visibility, either by ventilation or by lighting.

If the tunnel is short enough to make it into a single section, the absolute block can be used in the tunnel, the entry thereto being covered by a *stop* signal instead of a *stop and proceed.* Two trains running in the same direction could then never be in the tunnel at the same time, and running at sight would be unnecessary. There could be no difficulty about this, at least so long as the block equipment is working properly, but difficulty would arise in the event of the equipment failing, which would shew itself by holding the *stop signal* at the entrance to the tunnel in the *danger* position, and it would then be necessary to authorise the trains to run exceptionally past the defective signal.

The simplest solution is for this permission to be given by a pointsman permanently located at the entrance of the tunnel, after he has ascertained by telephone from his colleague at the other end that the preceding train has cleared the tunnel and it is therefore apparent that the signal is being held at danger through a failure of the equipment. The drawback of this method, of course, is that men have to be kept permanently on duty at each end of the tunnel, but it can be overcome by arranging for the permission to pass the *stop* signal at danger in special cases to be given telephonically to the train staff, say, by the « dispatcher ». This is the most economical solution, although the regulations required to give effect to it may be rather difficult to frame. It would be absolutely necessary for the stations to make no mistake in the identification of the trains when reporting them to the dispatcher as passing through, and this might not be easy in the case of through trains on busy sections. On the other hand this solution obviously restricts the capacity of the line, especially if the station advising the dispatcher is not close to the exit from the tunnel. In fact local considerations — minimum admissible traffic, in case of failure and proximity of neighbouring stations — decide which of the two solutions is to be selected.

The problem is especially complicated if the tunnel is long enough to require

dividing into several sections, with consequent installation of intermediate *stop and proceed* signals. It then becomes imperative on the one part to provide within the tunnel signals of very great visibility and on the other hand to avoid as far as possible prolonged stops within the tunnel, except when unavoidable, as for instance, through a breakdown. Certain of the Administrations consulted are interested in this question, but none has indicated any solution which has been proved in practice.

7. Working of the automatic block system. — Possible failures.

In conformity with the programme which we have laid down, it is not our intention to study in this report the technical features of the automatic block system; consequently, we shall not describe the various appliances employed.

We wish, above all, to examine the possibility of adopting various arrangements having for their object to guard against eventual failure of the apparatus. We shall confine our study to the case of automatic block signalling with track circuiting, in almost universal use.

The principle on which this type of block signalling is based is shewn in figure 1 is particularly simple (*).

It comprises a track circuit, limited by insulating joints *i, i,* at the entry to the section (see figure 1) and by insulating

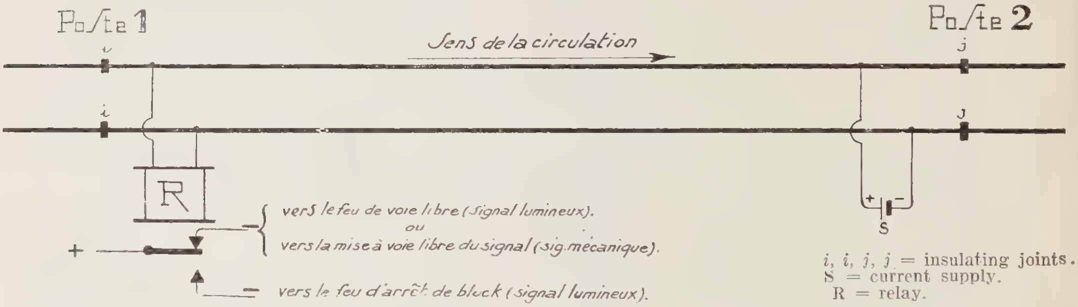


Fig. 1. — Diagram illustrating the principles of the automatic block with track-circuiting.

Explanation of French terms:

Poste 1 (2) = box No. 1 (No. 2). — Vers le feu de voie libre... = towards the *line clear* aspect (light signals) or the *off* position of the semaphore signal (manual block). - Vers le feu d'arret — towards the *stop* aspect (light signals).

joints *j, j,* at its exit. The circuit conveys to the track relay R, situated at the entry of the section, the current supplied by an electric source S (primary battery, accumulator, transformer...) situated at the exit. If the section is clear, the current flows to the relay which it excites, closes its upper contact, and thus establishes an electric circuit which holds the signal at the entry of the section (not shewn on figure 1) off if it is mechanical, or lights the « line clear » lamp in the case of a daylight signal. If, contrariwise, a train is in the section, the relay R is short-circuited and deenergized, and its upper contact drops, thus cutting off the current from the brake of the mechanical signal, which drops to the *on* position by gravity, or in the case of daylight signals cuts out the

(*) To simplify our report as much as possible, we shall not deal with the « warning » indication which the trunk lines give to a driver approaching a *stop* signal, but shall discuss a block system giving only two indications, « stop » and « line clear ».

« line clear » lamp, and, closing its lower contact, lights up the *stop* signal.

This system is designed — and it is one of its greatest advantages — so that all relatively probable failures (failure of current, broken wire, loose terminals...) have no other result than the neutralisation of the relay, even though the section is free, i. e., unnecessarily putting the signal to danger, consequently a useless stop, and a loss of time.

Might not certain failures, however, on the contrary have serious consequences? It is essential these failures be analysed.

There would be risk of accident, of course, if the *stop and proceed signal* remained at clear wrongly, while a train is standing in the section. This would occur if the signal remained *off* although the de-energized track relay may have dropped its upper contact. It could equally well occur if the track relay completed its top contact, notwithstanding the presence of a train within the section.

Finally, there is also a chance of accident, in spite of the signal at the entry to a section being *on*, if this signal is not obeyed by the driver, either because he has not seen it, or else, having seen it, has not paid proper attention to its aspect.

Let us examine these various suppositions in some detail.

a) Relay correctly de-energized, and having consequently broken its upper contact. Stop signal wrongly off.

It will be necessary to deal separately with colour light signals and mechanical signals.

In the case of colour-light signals — and this is one of their principal advantages — it is practically impossible to have a *line clear* indication when the relay in de-energized. The *line clear* aspect is in fact given by the upper contact of the relay, and this contact being broken, as unintentional illumination of this aspect could only happen if the wires leading to the lamp were crossed and unduly put under tension, and such a possibility is easily guarded against in the very short distance between the relay and the signal.

With mechanical signals the situation is different. The de-energization of the relay gives, as before, the practical certainty that no current is passing to the holding magnet of the signal, but, in spite of all the care devoted to the construction of the motor as well as of the signal itself, it can happen that sticking from one cause or another (bent shaft, want of lubrication..., and above all, frost) may hold the signal wrongly *off*, although no current is passing to the holding magnet. Therefore, certain railways have added to their automatic block installations with mechanical signals, a « continuity » device, making the feeding of the track circuit, and consequently the clearing of the stop signal after a train has gone by, dependent upon the following block signal having gone to danger, or failing this, on the clearing of the following section. Such a device, the principle of which is shewn in figure 2 is easily arranged. All that has to be done is to pass the feed for the track circuit from the source of supply S 1 through a contact C, made when the stop signal at box 2 is on. If then, the stop signal does not go to danger after the passage of a train, current from the supply S 1 does not pass to the track circuit, and although this latter is clear of traffic, relay R 1 remains de-energized, holding the signal at box 1 *on*. Moreover, another circuit, shewn by a dotted line on figure 2, enables the track circuit to be fed, when contact C is broken, if relay R 2 is energized, i. e., when the section between boxes 2 and 3 is clear. To sum up, the train is always covered by a signal at danger; within the box 1 — box 2 section it is covered normally by the signal of box 1; if the signal at 2 does not go *on* after the train has passed,

the signal at 1 continues to protect the train exceptionally during its passage through section box 1 — box 2.

This « continuity » device is ingenious, but its use is not without some drawbacks on account of the regulations

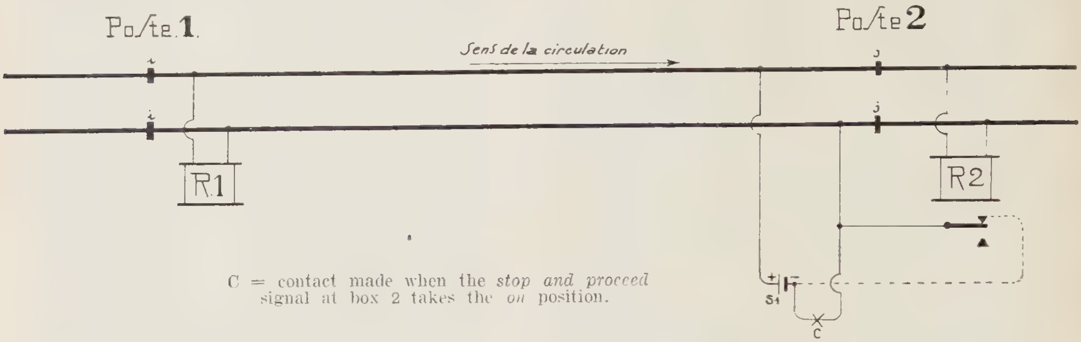


Fig. 2. — Continuity device for controlling the signal in the *stop* position.

necessitated. It is clear that if a stop signal requires the driver as is *normally* the case, to run at sight only within the section covered by this signal, the « continuity » device would be ineffective. The driver would run at sight through the unoccupied section, and would regain speed on arriving at the signal incorrectly *off*, i. e., exactly at the moment when it became necessary to run at sight. The continuity device, therefore, would have delayed the accident a little; it would not have prevented it.

To be effective, the block signal at danger must force the driver to run at sight through the *two* sections commencing with the signal at danger, but this requirement, only of use in the exceptional case of a signal at danger through the following signal sticking in the *off* position, definitely has its drawbacks in all the other much more numerous cases of a block signal being at danger. Its effect, is to prolong, uselessly, the time lost by trains meeting such a block signal at danger; furthermore, and what is most important, there is a risk of its resulting in the drivers becoming less attentive to the necessity for running very carefully *at sight*, particularly in the second section, which in practice will be found clear nearly always, but possibly also in the first section, where much care is absolutely essential.

To sum up, we think that, if the continuity device offers more advantages than drawbacks in certain cases where one might be afraid of a mechanical signal sticking at clear, it must not be lost sight of after all that this arrangement is only a palliative, and that certainly the better plan, wherever possible, and *particularly in new installations*, is to avoid using mechanical signals and use only daylight signals in automatic block working.

b) Relay wrongly making its upper contact, even though the presence of a train within the section prevents current flowing to it.

This could happen, either from a mechanical defect of the relay (bent pivot, damage to vane...) or to an electric defect (residual magnetism, upper contact fused and sticking...).

Devices could be used which would avoid the consequences of such a relay failure. For instance, one might provide a continuity device (of the same order as that we mentioned above) only allowing the clearing of the block signal after

the passage of a train if the relay at the further end of the section has been de-energized by the passage of the train. This system is considerably more complicated than the first continuity device already examined. Figure 3 shows one

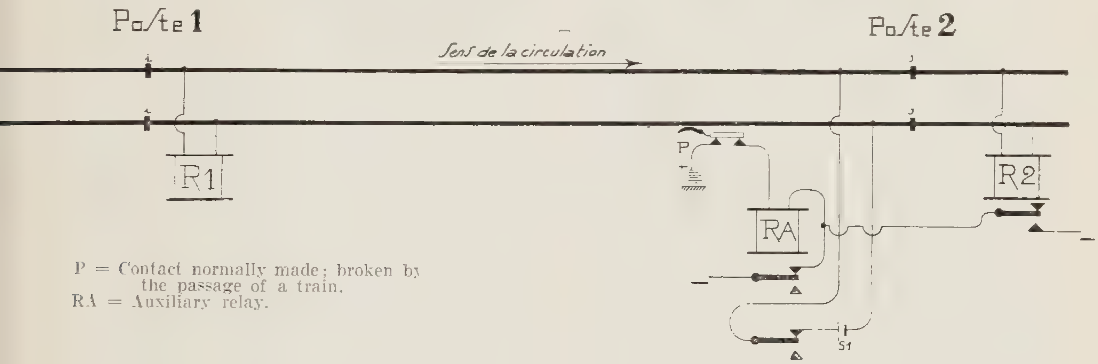


Fig. 3. — Continuity device for controlling the de-energization of the relay.

method of doing this. Current from S 1 can only pass to the track circuit if an auxiliary relay R A is energized. This relay is energized after the passage of a train, if the track relay R 2 is properly de-energized. After re-energization of the relay R 2, when the corresponding section is clear, the relay R A remains energized, until the following train has passed over the treadle P.

An arrangement of this kind materially increases the possible number of times the block signal is at danger untimely. This is certainly a serious drawback, on the one hand because of the resulting delays and on the other hand, because of the danger of the drivers in the long run thinking that the block signal is at danger through a failure of apparatus, and not through the section being occupied.

Like the previous arrangement, it has the drawback of requiring every driver passing a block signal at danger to run at sight through *two* sections.

Following a different line of thought, one might double all the track relays, under such conditions that the de-energizing of one only of the two relays is sufficient to put the signal at danger, whilst the excitation of both relays is required to take the signal off. Unlike in the preceding case, this system does not call for any modification of the regulations; it allows the logically consistent rule being preserved of only requiring running at sight within the single section covered by the signal at danger, but, on the other hand it augments the number of times the block signals wrongly go to danger, which, as we have just seen, is a serious drawback. Also, it increases the difficulties of regulating the track circuits, and compels their average length to be considerably reduced, so much so that the number of relays be increased not twice, but four times. This solution then becomes very costly, and, if used, necessarily reduces considerably the track mileage which can be fitted with automatic block signalling for a given expenditure.

With relays of present-day design the relay contacts, however, rarely stick up when no current is passing through and, remembering the drawbacks of the schemes suggested above, we agree with the majority of the railways using automatic block working that, instead of

taking precautions against such failures, the better plan is to use good relays, which never stick up in service.

In putting forward this opinion, moreover, we remain in agreement with the recommendation of the Madrid Congress in 1930, in Summary V of Question XI relating to automatic block working, as follows : « the tendency is towards simplification in working methods, which, without diminishing safety, shall reduce to a minimum delays due to failures or irregularity.

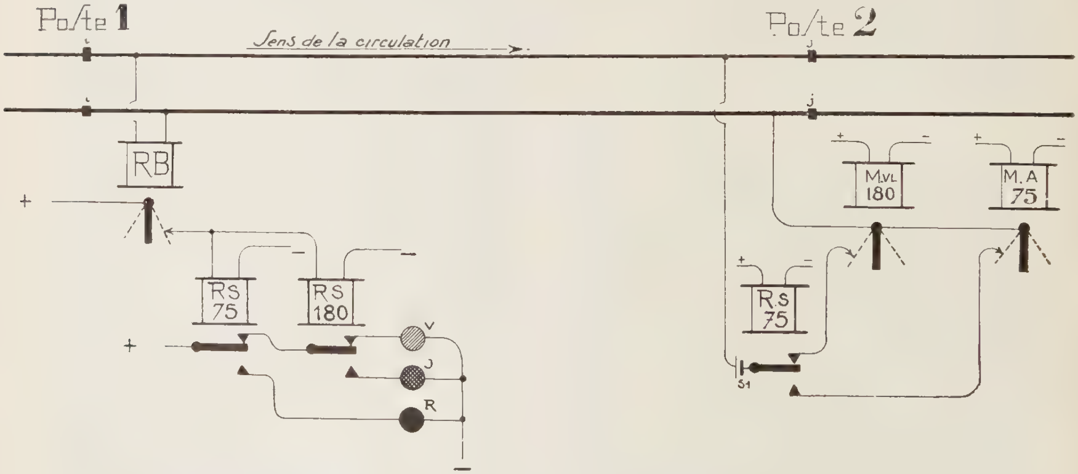
c) Relays working properly, but receiving current (and consequently clearing the signal) in spite of the presence of a train within the section.

Various causes may produce this result; we will examine the most likely.

c 1) The track relay of a section is always close to the current supply of the section ahead of it. One may imagine that, if the insulating joints separating the two sections were to become conductors, the track relay of this section would become energized by the current from the section ahead, notwithstanding the presence of a train at the back end of the section ahead. In practice, this eventuality is prevented by using well insulated joints, and to some extent by reversing the polarity of the supply of adjacent sections.

c 2) The track relay of a section occupied by a train can sometimes be energized by currents completely independant of the signalling supply, as, for instance, by stray currents coming from a nearby electric tramway. The necessity of taking steps, on electric railways, to prevent the return traction current from wrongly energizing a signalling relay, is only a particular instance of this problem, the general solution of which evidently consists in using for signalling purposes relays which will be insensible to the disturbing current to be feared. Consequently one is led to employ for signalling A. C. relays, which are insensible to D. C., if the disturbing element is D. C., and D. C. relays insensible to the frequency of the disturbing current, if that itself is A. C.

An interesting solution of the problem of protection against stray currents is



V = Green light = line clear.
J = Yellow light = caution.
R = Red light = stop.

M.A.. M.V.L. = Code transmitters.
R.S. = Selector relays.
R.B. = Surging relays.

Fig. 4. — Diagram illustrating the principle of the coded track circuit.

provided by the use of « automatic block signalling with coded current », usually more simply described as « coded track circuit ».

Thus, track-circuited block signalling is so termed when the current for the track circuit is « coded », i. e. interrupted a certain number of times per minute according to a frequency which depends on the state of the road. Figure 4 illustrates the principle on which this type of block signalling works. As in the standard system of track circuiting, there is at the outgoing end of a section a source of supply, D. C. or A. C., represented by S 1 on figure 4. Again as in the standard system, this current is fed to the track at the extreme down end of the section always, but instead of being on permanently, it passes through a « modulator » (or code transmitter) which interrupts the current a certain number of times per minute. If we take the case of a three-indication signalling system giving — stop, caution, line clear (*) —, there are two modulators, one MVL interrupting the current 180 times per minute, for example, and used when the signal at box 2 is not at stop, the other, MA, cutting the current 75 times per minute, used when the signal at box 2 is at stop (the proper modulator is switched in easily by means of a top or bottom contact of the relay RS 75 controlling the signal at box 2). There is a track relay RB of a special type at the beginning of the section. This is a surging relay, which does not make contact when no current is passing through, but gives impulses at the frequency of the current it receives, either 180 or 75 times per minute, according to whether the signal at the box ahead is off or on. Finally, at the entry to the section there are two « selector » relays RS 180 and RS 75. Relay RS 180 makes top contact only when fed by a current of 180 cycles. Relay RS 75 makes its top contacts when it receives current at either 75 cycles or 180 cycles.

The working of the system is very simple. If there is a train or vehicle in the section no current passes to relay RB; the two selector relays are both de-energized, and the block stop signal is lit by the bottom contact of RS 75. If, contrariwise, the section is clear, relay RB is energized, and makes and breaks continuously at the code frequency of this current. If the signal at box 2 is on, the modulator MA 75 pulsates the supply to the track circuit; the relay RB thus continues to make and break the current at 75 times per minute; relay RS 75 is energized, relay RS 180 remaining de-energized, and the signal shows the *caution* aspect. Lastly if, the section being free, the signal at box 2 is not *on*, the *selector* relay RS 75 at box 2 is energized; the modulator MVL 180 is working at this box; the relay RB makes and breaks continuously at the rate of 180 times per minute, the two relays RS 75 and RS 180 make upper contact simultaneously, and the signal gives the *line clear* aspect.

The advantages of the coded block system are many. It is clear, in fact, that if, as with the standard system, it is designed so that failure of its apparatus cannot give *line clear* wrongly (for instance, if a modulator failed the block signal would not go to danger prematurely) it also gives, unlike the standard system, a practically absolute security against stray currents. Line clear results in fact from the relay RB pulsating continuously 180 times per minute, and obviously stray currents as a rule are not coded at that frequency. Again, the coded block gives complete safety against a faulty relay making top contact prematurely. Further, this system is more sensitive than the standard system; certain vehicles which only give a partial short-circuit, stop the surge relay, and consequently

(*) We are now no longer dealing with the two-aspect signalling which we have discussed heretofore (see footnote on page 146/10).

cause the block signal to go to danger, but would not de-energize a relay of the standard system. Finally the coded block system — we will return to this point — lends itself quite specially to cab signalling.

c 3) The track relay can be energized and clear the block signal in spite of the presence of a train within the section, if the axles of this train do not set up, between the two rails of the section, a shunt of sufficiently low resistance to cause the track relay to be de-energized.

In practice there is no difficulty in positively de-energizing a track relay when an actual train passes by (*). On the other hand, this difficulty arises at once with railcars fitted with pneumatic tyres, and even with certain light vehicles (railbuses, trolleys...) with steel tyres.

Certain railways only allow such vehicles to run when the stations are instructed to protect them by using the absolute stop signals under their control, and by using the telephone block system.

Other railways fit these vehicles with shoes connected electrically, and in permanent contact, some with one running rail, and the remainder with the other rail. It is possible, at least when these shoes are carefully adjusted, to get a satisfactory short circuit but they have the drawback of absorbing a good deal of energy.

These difficulties have led the railways to make sure the track is properly short-circuited, even with vehicles which short-circuit badly, by using more sensitive relays. We cannot undertake to examine here in detail all the arrangements which have been tried out, as this would take us outside the limit we set to ourselves. We would merely state that certain of these arrangements have improved the technique of short circuiting considerably.

d) Finally, the signal, although at danger, can be read incorrectly by the driver.

We will not go into the question here of a driver who does not see the signal (as this is a matter which is not peculiar to block signalling, but applies to all signals, and which will be looked into in the latter part of this report), but only the case of a driver who, having seen the signal, has not observed its aspects correctly.

This is in fact an actual experience; on all railways using automatic block signalling, drivers understand very well the regulations on running at sight, and on the whole respect them. We think, however, attention should be drawn to one weak point. On various railways, a train stopped before a signal at *line clear* has been run into by the following train, the driver of which, after having run correctly at sight over nearly all the block section, has increased his speed a little too soon, on seeing in front of him the *line clear* signal, but not noticing the presence of a train in front of this *line clear signal*. It seems that certain drivers, seeing a *line clear* signal at the exit from a section tend to forget the order to run at sight, which should be scrupulously respected throughout the whole section, i. e., until having actually run past the signal at the exit of the section. It is our opinion that drivers should be very carefully instructed on this point.

8. Results.

In general they are excellent.

We have just reviewed at length the failures possible with automatic block signalling; that is the duty of the signalling engineer, but the reader should guard against gaining a false impression from this lengthy study. In point of fact, failures are *extremely rare*, and practi-

(*) Difficulty occurred, however, at certain particular points, such as where drivers use the sanders. At a few of these particular points treadles have supplemented the track circuit.

cally non-existent with recent installations, particularly those with light signals. They are certainly much rarer than in the case of manual block signalling, so much so that all the railways which are extending their automatic block signalling are unanimous in placing *increased safety* amongst its principal advantages.

Further, it is equally incontestable that automatic block signalling increases the capacity of the lines owing to the very quick operation of the signals, which, after a train has passed, clear immediately as soon as it can be safely done. On many sections of busy lines, particularly in the suburbs of big cities, the existing service would be practically impossible if it became necessary to abandon automatic block signalling and revert to manual working.

Lastly, automatic block signalling carries with it economy of personnel. It is true it often increases maintenance costs, but it is beyond doubt that it definitely reduces running expenses, always considerable, when compared with manual block working for the same traffic capacity. Automatic block signalling is in fact the only system in which it is possible to multiply the signal boxes without incurring the expenses on staff for manning them.

* * *

PART TWO.

Power boxes.

By power boxes we mean those signal boxes in which the operation of the points is effected by an electric motor, hydraulically, pneumatically, etc., and not manually by the signalman.

The very numerous power boxes (some 1 000 on the railways which have replied to our questionnaire) are of most varied types, and the present chapter of our report is that in which it is the most necessary — to avoid too great length — to confine ourselves to considerations of operation, independently of any technical study. We will examine successively :

— power boxes properly so called, i. e. those which use a separate circuit to operate each switch;

— points operated from a long distance by means of special devices reducing the number of operating and control circuits.

— automatic operation of the points by the trains themselves.

1. Power boxes properly so called.

These boxes are divided into two classes :

— boxes with *individual levers*, in which the signalman moves a lever for each point or signal operated. When setting the road for a train, the signalman, therefore, as in cabins which have no power, has to move in succession the various point levers concerned in order to set the points correctly, and then move the levers of the signals which allow the train to pass.

— boxes with *route levers*, in which signalmen have only one single lever to move in order to prepare the road for a train. The moving of this single route lever suffices to set the different points concerned into the correct position, and to take off the signals. The French main-line railways alone have a large proportion of signal boxes equipped with route levers. The other railways have relatively fewer, but it would seem that the actual tendency on the greater number of railways which we have consulted, is to instal route-lever plants.

This would appear to be justified, for :

— on the one hand, route-lever installations are always much easier to work than installations with separate levers, in which a great number of lever movements are needed to set up a route.

— on the other hand, two types, at least so far as modern installations are

concerned, tend to become equally complicated, installations with separate levers usually incorporating on the lever of the signal giving access to a route, a device for controlling the whole of the points on this route.

We have noted also another tendency which we think it desirable to point out. That is the tendency to use in power plants « miniature » levers, reduced to a very short handle often placed on a diagram of the area controlled in the position representing the location of the points which it operates, in the case of a separate lever installation, or the signal covering the route, in the case of an installation with route levers. This we consider should be developed as it makes the task of the signalman particularly easy.

A final point appears to us to be worthy of attention. This is the tendency to replace the electric devices locking the point lever by cutting off the current to the operating circuit of this apparatus. If, for example, it is desired to prevent a stop signal being taken off, instead of locking the lever of this signal in the *on position,* it is frequently the practice to-day to cut the circuit of the relay clearing the signal though its upper contact. This procedure is to a certain extent less convenient to the signalman, as, if he happens to attempt the operation of an interlocked switch, he no longer feels, as before, the resistance of the lever, and can only find out his error by noting, after examining the control devices at his disposal, that the points do not answer to the lever. Notwithstanding this, it does appear to be an improvement from the point of view of safety. The breaking of the circuit is, in fact, habitually done at a relay, and the functioning of a relay is still more regular than that of an electric interlock.

Similarly, one has got as far as replacing, by the interruption of the control circuit of the apparatus, the purely mechanical interlocking of the levers which have hitherto been used — and are still frequently — by breaking the operating current to the points between their levers. This elimination of the mechanical locking is not as interesting as the suppression of electric locking apparatus, seeing that mechanical locking is a very reliable safety device. The interruption of the working circuits at least gives equal security, and this latter system is, in practice, the only possible one in the case of miniature levers, which could not easily move over the interlocking gear.

a) Safety devices usualy found in power boxes.

These are many and very diverse. The most important are the following :

— *Positive point control,* i. e. arrangement ensuring that a signal can only be taken off when the switch tongues concerned are in their correct position.

This particularly important arrangement can be carried out either under the form of « temporary positive control », or that of « permanent positive control ». In the first case the signal can only be taken off if the points are set correctly, but once off it ceases to remain subordinated to the position of the points, so that if the points should be moved after the signal comes off, the latter would not return to danger. On the other hand, in the case of « permanent positive control » the signal remains permanently dependent upon the points, and the displacement of any point would restore the signal to danger if it were *off.* The second system is evidently safer, and moreover, is much more widely used.

Positive control of the signals in the « on » position, i. e., an arrangement whereby a signal cannot be taken off to allow any movement whatsoever, when the signals protecting this movement are correctly *on.*

Like the preceding one, this arrangement can be carried out either as « temporary positive control » or « permanent positive control ». Both systems are met with in power boxes. As in the first case dealt with, it is evident that permanent positive control is the better solution. It might be as well to point out, however, that many power boxes, even modern ones, only use the temporary positive control of the *on* position of the signals.

— *Route and approach locking.* By route locking is meant an arrangement whereby the placing to danger of a signal behind a train is not sufficient for the signalman to take off another stop signal, permitting the arrival of a train which cannot pass at the same time as the first. Arrangements of this nature are found in practically all power plants, but they are carried out in very different ways.

In certain boxes each of the pairs of points is directly locked, whilst any train occupies an insulated zone in the immediate neighbourhood of these points.

In other boxes — and the method is especially suitable for boxes controlling a wide area with points far apart — the route interlocking is easily provided as follows : as soon as a train passes the absolute stop signal at the entry to a route, all the points on it are locked in the position which they occupy, until the train has cleared it. This arrangement gives full safety, but may become troublesome in boxes where many movements are made. The equipment has then to be complicated, for example by dividing up each route into several partial routes, each forming the simple route of which we have just spoken, or supplemented by route-cancelling devices under the control of the signalman, the use of which may have drawbacks.

In yet other boxes, a simple time device is used, which locks all the points of a route during a certain period the moment when a train starts over this route, and releases them automatically at the end of the predetermined time even if, in exceptional cases, the train has not yet cleared it entirely.

Finally, in certain modern boxes, a flexible route has been worked out, which is certainly the best solution from the operating point of view. In this system all the points of a route are locked in the position which they occupy directly a train passes the stop signal at the entry to a route, but each of them is released as soon as the tail of the train has cleared it. Consequently, this device only comes into action in the sole case of a signalman attempting by mistake to set up a route before this can be done in safety.

Approach locking is the locking of the various points on a route, not only when the train passes the absolute stop signal at the entry to this route, but a little before the train passes the distant signal applying to this absolute stop signal. Like the route locking itself, approach locking is carried out in very different ways.

Sometimes it is simply an extention of the route locking which, as we have just said, commences purely and simply in front of the distant signal, instead of at the stop signal. In other cases it is so arranged that, during the whole time that the train is within the zone of approach, i. e., the zone beginning a little before the distant signal and ending at the stop signal at entry of the route, the route locking prevents this signal being placed at danger (*) by the signalman. This second system is in our opinion the better, for it makes it impossible for the signalman

(*) At least by the usual procedure, for obviously the signalman must be given the means of putting the signal at danger in urgent cases, for instance, against a train arriving at speed, in the case of the track being obstructed by a derailment on an adjacent line.

to put the absolute stop signal on by mistake against a train which has passed the distant signal at clear.

This question of route and approach locking is definitely complicated, and is carried out in very different ways; obviously each concrete case must be examined specially, and the best method only selected after considering the area controlled by the signal box, the number of movements to be covered and the nature thereof (passing trains or shunts) the operating method used elsewhere (for instance, the existence of automatic block signalling with track circuits) the capital available, and the skill of the maintenance staff.

b) **Failures.**

The question of power box failures is a delicate one. As with all safety devices, such failures must, in practice, be on the side of safety, that is to say, they can prevent the clearing of a signal which might be cleared without danger, but never allow the clearing of a signal which ought to remain *on*. This feature is secured in fact in modern installations, when they are properly maintained, and consequently, in the following, we shall only deal with these failures on the side of « safety », which prevent a movement being carried out which might be made without risk.

The first question is : Is it advisable to cancel the defective electric lockings, i. e., to place in the signalman's hands the possibility of cutting out these lockings? In certain cases cancellation is inevitable; that is the case of the whole of the locking of a pair of points, the failure of which would render impossible every movement of these points. On the other hand, cancellation of the lockings which prevents the clearing of the signals may also not be provided for; one can, in fact, continue operation by specially authorising trains to pass signals at danger owing to a failure of apparatus. This is not without its drawbacks, in the first case from the psychological viewpoint — as if the drivers are scrupulously to respect the *stop* aspect of a signal, they must practically never receive an order to pass it. On the other hand, from the technical point of view, for, at least in certain installations (in practice those in which the interlocking is obtained by immobilising a signal lever) the cancellation allows all other lockings to remain uncancelled, in particular the mechanical lockings. Therefore, we agree with the great majority of railways, that if an electric lock fails, it should be cancelled.

What precautions ought to be taken when cancelling an electric locking ? First and foremost — and all the railways insist on this — it is necessary to make sure, before cancelling, that no risk is attached. If, for instance, it is a question of cancelling the locking of the positive control of facing points, one must ascertain first if it is really a failure of apparatus, and that the tongues of the points concerned are lying in the correct position. The cancelling device should never be brought into action until *after* this verification has been made carefully.

Ought one have entire confidence in the man who has made this verification, and can one, after cancelling the defective electric locking, clear the signal under the same conditions as if everything were working properly, allowing trains to pass at any speed ? Some railways allow this procedure; the greater number on the contrary — and we think that this is usually more prudent — hesitate to go so far, and only allow the cancellation to be made *after having stopped the train*. This procedure offers two advantages; on the one hand it adds materially to safety in the event of a signalman committing the serious fault of cancelling without having made sure, if need be on the spot, that it is a question of failure of apparatus, and that all the

conditions allowing the passage of a train are existing, notwithstanding that the signal cannot be cleared; on the other hand the repairs can be carried out more rapidly. It would, in fact, require remarkably conscientious maintenance men who would carry out the repairs with the maximum speed, if all the time the trains were running normally, without losing time.

How can the cancellation device be best operated ? In many cases one finds devices which, placed in the cancelling position, cancel purely and simply the locking during the whole time they remain in that position. In a few modern installations, on the contrary, « reiterated » cancellations are used exclusively. This name is given to devices in which the cancellation produced by operating them affects only one single operation of the signal. After the operation of this signal, the cancellation is automatically nullified, and a new movement of the cancelling device has to be made before *each* operation of the signal, the electric locking of which is out of order. In our opinion « reiterative » cancellation is a marked progress. It constitutes in fact the best means of insuring that, at *each operation* of the signal the attention of the signalman is drawn to the fact that one of the electric lockings of this signal is out of order, and it would be advisable that certain essential checks should be made before allowing a train to pass.

Finally, which employee should be authorised to operate the cancelling instruments ? On this point again one meets with different procedures. Some railways lay down that the cancelling devices shall be always operated by the maintenance staff. Others entrust them to the signalmen. We think that again this is a problem which cannot be perfectly solved everywhere under the same conditions. Its solution may depend on the intensity of the traffic, and on the degree of confidence which, on a particular line, can be placed in the various grades of employee. It may even vary from one case to another within the same railway system. We think that, usually, the better practice is to entrust the cancelling devices to the signalman, or, if he is not sufficiently educated, to his chief, but not to the maintenance staff. In this way, the defect is righted most quickly, for the maintenance man might be engaged elsewhere at the time of the failure; also, the signalman, or his chief, who is not responsible for the maintenance of the apparatus, is less likely to be tempted to conceal a failure by not stopping the train, in spite of this being the rule.

To sum up, this review, short though it be, shows how very important it is to look into this question of failures. Whatever may be the solution adopted, there is no doubt that it is a serious matter if failures are frequent. All the railways are unanimous in stating that, from this point of view, modern installations are giving them entire satisfaction, and that their working is very reliable.

2. **Distant operation of point and crossings** *by means of special devices for reducing the number of operating and control circuits.*

These arrangements are diverse enough, and cannot be described in detail here. It should be noted further that they are not safety appliances in the sense in which this word is used habitually on railways, but only transmitters of orders. All the locking arrangements necessary for the safety of the traffic are made *on the spot* between the relays operating the various instruments, under conditions comparable with those one meets with in ordinary power boxes in such wise, that the failure of the special instrument merely results in the impossibility of operating

one or several points, but never by creating a situation endangering the safety of the traffic.

The employment of such devices is above all interesting when they do away with the necessity of installing a large number of track circuits of great length. In fact the two most common cases of application are the following :

a) Operation of the points at a junction between a branch line and the main line from a neighbouring station, or by the train dispatcher.

If the junction is a simple one, and if it can be operated from not very far away, there is not often much object in using a device to reduce the number of operating and control circuits. On the other hand, such a device certainly becomes economical if the distance is great and if the junction is complicated. A detailed study of each particular case is indispensable if the best solution is to be found. Amongst recent interesting installations of this nature are the four « semi-autonomous » boxes on the French Est Railways, by means of which a station controls junctions on the main line at distances up to 4.4 km. (2.7 miles). The station controls a particular pair of points through selectors of the usual automatic telephone type. These boxes are giving entire satisfaction.

b) Points and *stop* signal operation by train dispatchers on sections of line over which trains are run in both directions.

This operation is usually done on the centralised traffic control system, using operating or control « codes », consisting of a series of long or short impulses, following each other according to the particular code of the points to be operated. Many applications of this system have been made in America, both on single-track lines on which the traffic has become too heavy to allow of their operation by the old methods, and on double-track lines which it can sometimes be found advantageous to work as two single-track lines.

So far this system is not much used in other parts of the world. Its most important application outside America on the railways consulted is between Houilles and Sartrouville, on the French State Railways suburban lines from Paris-St. Lazare, where a section of three-track line has an *up line*, a *down line*, and a *central* line over which the train dispatcher passes the trains in one direction or the other according to need. This installation, laid down in 1933, is giving entire satisfaction.

Centralised traffic control is, in our opinion, bound to develop in other parts of the world as in America, and when a railway finding one of its lines overweighed with traffic is forced to enquire whether it would not be advisable to add a new line (doubling a single track line, or trebling or quadrupling a double-track road) it should, we think, first look into the solution offered by centralised control.

3. Automatic operation by the trains.

Clearly such equipment can only be employed, for the present at least, when the track layout is very simple (*). As regards the railways which replied to the questionnaire, automatic points ope-

(*) We are not including in this review the case where the driver of a train which has stopped in a station for instance, himself operates the points of a junction towards which his train is to run. This arrangement allows in certain cases the suppression of a signalman, but it is not automatic operation : the driver acts as a signalman.

Nor shall we deal with the operation of the points in a marshalling yard, which is effected by the wagons themselves, but under conditions which, for each marshalling operation, have been decided upon and prepared in advance by an operator : it is this man who is the signalman.

ration has been used in the two following cases only :

a) In the United States of America, there are some crossings without points, at which there is no signalman. The protecting signals are normally *on*; when a train approaches, it clears automatically the signals of the line over which it is running, of course only if the signals of the other lines are on. This very simple arrangement gives entire satisfaction. It cannot, however, be used much, as there are few cases of two lines crossing one another without intercommunication.

b) The New Zealand Government Railways have, under similar conditions, several instances of the automatic operation of the points and signals, at the junction of a single track line with the double track line. The French State Railways have several installations of « automatic terminal shunting », in which the trains themselves actuate the signals and points requisite for the movement of a train, which has arrived, say, from the *down* road of a double line, runs into a dead end siding, then leaves in the reverse direction on to the *up* track of the double line.

These again are simple installations, which give every satisfaction to the railways using them. We think that the use of this second type of automatic operation is more likely to grow than that first examined.

* * *

PART THREE.

Locomotive cab signalling equipment.

In the early days of railways, the engines were not fitted with any device for calling the driver's attention to the fact that he was approaching a signal at danger, or for applying the brake if he was not using it properly. Safety therefore depended on the vigilance of the driver alone; if that was wanting, there was nothing to make it up, and an accident became possible.

For a very long time, the question of assisting the driver to observe the signals has been under consideration. Mr. G. H. CROOK, one of the Reporters on Question IX of the 12th Session, held in Cairo in 1933, recalled in his review that, as long ago as 1857, a Mr. Kendall had taken out a patent for a device to repeat the signals on the engines.

The simultaneous increase in speeds, in boiler sizes and in the number of signals has rendered less and less easy the proper observation of the signals by the drivers, so much so that the question of the repetition of the signals on the engines is becoming more and more important, particularly within the past twenty years.

No other signalling question has raised so much discussion; no other is so delicate. Anything which can assist the driver in observing the signals is unquestionably an advance in practice, and the adoption of a signal repeating device on the engine could not give rise to any objection in principle (apart from the very heavy cost of certain systems), if this repetition were assured by perfect equipment which would never fail, or at least failed on the side of safety, i. e. sometimes giving the *danger* indication needlessly, but *always* giving the driver that indication when it is necessary.

However, designing perfect equipment is difficult; it has been for a long time impossible. As any repeating device always involves a risk of the driver being less vigilant, through, as is natural, relying to some extent on it, one might ask if actually its use may be questioned as possibly being more dangerous than useful. The hesitation of many Signal Engineers in accepting the principle of repetition under these conditions is un-

derstandable. A perusal of the discussion on this question at the Rome Congress in 1922 brings out these doubts clearly.

* * *

This preliminary review brings out the qualities which locomotive cab signalling devices should possess : they should work really well, and their rare failures should be on the side of safety, as we have already stated; further they should be designed so that there would be no risk of the driver's vigilance being lessened.

The question will be dealt with in three parts : we will study first of all *signal repeating equipment,* intermittent in action, and only operating when passing the signals. We will then examine *continuous signalling* equipment, which keeps the driver continually advised of the state of the road, and what he should do to assure the safety of his train. Finally, we will examine the *automatic application of the brakes,* a safety precaution which can be added to either of the above two systems.

1. Repeating the signals.

We will deal with the following questions in turn : what signals ought to be repeated; in what position should they be repeated; what is the nature of the indication to be given to the driver; what steps should be taken so as not to lessen his vigilance; on what principle is the equipment based — it being understood that this chapter only deals with those systems which *give the driver the signal indication* and do not apply the brakes automatically.

a) What signals ought to be repeated ?

The signals, the repetition of which is most desirable on the engine are clearly the ones most difficult to sight, i. e. those at which the driver running at high speed may have to apply his brakes. All the railways agree that distant and « reduce speed » signals at danger should be repeated.

The repetition of *stop* signals, or *stop and proceed* signals when *on,* is much less important, since these signals are only approached by the trains after a distant signal at danger has been passed and repeated in the cab. Railways using intermittent repetition actually do not repeat the stop signals. The French Nord however repeats on the engines the automatic block *distant* and *stop* signals when at danger, by means of the Ledard device.

Further, some railways — amongst them all the French railways in particular — always apply detonators when the stop signal is at danger.

b) In what position — « on » only, or « on » and « off » — ought the signals to be repeated in the cab ?

In practice the two methods are used. Many railways inform the driver when he passes a distant signal at danger, but give him no indication when such a signal is clear. A priori this plan is very logical; it seems useless to advise the driver when he has passed a signal in the off position, since he is not then called upon to take any particular action, but is free to continue his journey in the normal manner. This would be the case were the repetition devices perfect, but as we shall see later (§ *e*) the instruments can fail, and sometimes fail to repeat a signal at *danger.* Some railways, therefore, repeat the signals in the *off* position, as a means by which the driver can make sure when passing each of the signals (*on* or *off*) be encounters that the repeating device (or at any rate part of it) is in good working order.

c) What kind of indication should be given to the driver ?

All railways agree in providing an *audible* indication when passing a signal at danger, as it attracts the attention of

the driver more surely than a visual indication, which is only effective if the driver is looking in a given direction at that moment. Naturally if an audible indication is also given when passing signals in the *off* position, it must be very different from the first, and not very loud, otherwise it would very soon bother the driver who, it must be remembered, on express trains passes a signal every minute, or even sooner. A satisfactory solution is that recently adopted by the French Nord in automatic block working, where an *on* signal is repeated by a powerful whistle, but an *off* signal by the noise made by the air espacing from the pneumatic device recording the signal positions.

At the same time as the signals are *repeated,* should the positions in which they are passed be *recorded* on the engine, on a paper roll for instance ? Two procedures are in use.

Certain railways make no record, and there is no doubt that this system, which has the advantage of simplicity, has no serious drawbacks. It is evident that the main object of a safety device is to avoid accidents (the recording is not done for this purpose), and not to let one know what happened, after an accident.

On the other hand, other railways record the position at which the signals were passed. We again find two systems : one recording only signals passed at *danger,* and the other the passing of signals at *danger* and in addition — of course by a different sign — signals passed in the *off* position. Such recording is not without its advantages, especially if it applies to all the signals. By examining the paper rolls a watch can be kept — somewhat late it is true — over the working of the repeating devices; also, viewed from a totally different angle, it facilitates enquiries and renders it impossible for the driver to dispute the position of the signals he has run past. This, we consider, is one of those problems the best solution of which is not necessarily the same on all railways, because it depends on the customs and traditions of the staff.

d) **What steps should be taken to prevent signal repetition on the engine lessening the vigilance of the driver ?**

The means to be employed is evidently to require the driver to perform an act, which *leaves a mark, before* running voluntarily past a signal at danger, in such wise that subsequently it is possible to check if he has, as he ought to have done, noticed the signal before running past it, or if, on the contrary, his attention was drawn to his passing the signal at danger by the cab repeating signal.

When signals passed at danger are recorded, nothing is easier than to require the driver, as a proof of his vigilance, to operate a lever, the movement thereof being recorded on a paper roll. This in fact is what all the French and Belgian railways do. By this means the driver retains a personal interest in properly observing the signals without relying on the repeater, for he will be punished if an examination of the roll after the engine has returned to the shed shows a signal has been passed at danger without being preceded by the vigilance mark.

In the absence of a recording device, it is equally possible to verify the vigilance of the driver when the engine is fitted with an automatic braking device. We shall return to this point shortly.

e) **Principles of the repeating apparatus.**

A great variety of designs are available. So as to keep this report within reasonable limits, the devices will not be described in detail, but their characteristics will be given and interesting points from the traffic point of view noted. All systems include a track fitting and an engine fitting to actuate the engine equip-

ment when running past the signal, of course in different ways when the signal is *on* or *off*.

e-1) **Mechanically operated devices.**

These designs were the first to be tried. Normally they repeat signals in the *on* position only, and include the following main parts :

— in the track, a pedal, connected to the signal to be repeated, in a predetermined position, down for instance, when the signal is *off*, and up when the signal is *on*.

— on the engine, an oscillating member, passing over the treadle without touching it if the signal is *off*, but striking it when the signal is *on*. The shock displaces the oscillating member on the engine, and actuates the repeating device.

There are many and grave drawbacks to this system. The presence of a treadle connected to each signal increases the labour for operating the signal, and introduces also the possibility of the signal sticking in the *off position;* this treadle is particularly inappropriate in the case of day-light colour signals, now very widely used, since its operation would require a special electric motor; lastly, experience shows that, at least at high speeds, it becomes practically impossible to ensure the regular working of the system, owing to the shocks between the treadle and the oscillating member.

As a result mechanical contact systems have not been generally adopted by any large system. They are only used on certain suburban lines where the maximum authorised speed is low.

e-2) **Devices depending on electric contacts, giving the « signal on » indication by the emission of current.**

This system consists of :

— on the track, a fixed bar of metal, the « ramp » connected to an electric supply through a switch actuated by the signal or, in the case of an electrically operated signal, by means of the relay controlling the signal;

— on the engine, a fixed metal brush, which sweeps along the ramp, and picks up current if the latter is energized. The current picked up by the brush is used to actuate the repeating instruments, and possibly the recording gear, or even to apply the brake.

Unlike the preceding, these devices are very widely used. They are to be found on the Belgian Nat. Rys. Co. and particularly on all the French Railways, which have fitted them on all lines of any importance, and on nearly all their engines. On these various railways the ramps are alive (positive current) when the signal is *on*; when the signal is *off* they are alive (negative current) for the railways which record the *off* and *on* signal positions, but dead on those railways which record only the *on* signals. The positive current picked up from the ramp by the engine brush sounds the whistle which repeats the *on* signal, at the same time as it records the passing of the signal.

The drawback of this arrangement is immediately apparent. The « signal *on* » indication is given to the driver by the positive current picked up by the brush from the ramp, therefore by the *emission* of current. If at the time the train runs past the *on* signal any failure (broken wire on the engine or at the signal, damaged brush, broken battery, hoar frost insulating the ramp from the brush, etc...) prevents the current passing to the engine, the *danger* indication is not given to the driver, and if he has not seen the signal, there is nothing to draw his attention to it.

However, in spite of this drawback, the ramp gives good results, thanks to the many precautions attached to its use in practice :

— very careful maintenance;

— ramp treated with parafin to prevent the formation of hoar frost, or

sufficiently hard brushes to sweep away hoar frost;

— on certain railways the *off* and *on* signals are repeated to enable the driver to see, on passing each signal, that the device is working properly (*); on other railways which only repeat the *on* signals, a device is used to call the attention of the person operating a signal if the ramp of this signal is not alive;

— the installation at the exit of each engine shed of a test ramp always alive; if an engine passes over this, the repeater should sound as when running past an *on* signal, thus giving the driver a means of knowing that, at that moment at any rate, the apparatus on his engine is working properly;

— on certain railways, installation at every 50th kilometre of main line of test ramps always alive, like those at the sheds;

— careful examination of the rolls on the engine, on which the repetition is recorded.

e-3) Devices making electrical contact and giving the « on » indication by interruption of current.

These systems include :

— in the track a ramp like those we have already dealt with, but dead when the signal is *on,* and alive when the signal is *off.*

— on the engine a metal brush rubbing over the ramp and picking up current from it if it is alive. Further the engine carries a relay normally energized by a local supply, the bottom contact of which closes the circuit which operates the repeating device of the *on* signal when the relay is de-energized.

When the brush passes over a ramp it is displaced slightly, which brings a switch into action and cuts the circuit of the relay of which we have just spoken. If the signal is *on,* the ramp is dead, the brush does not pick up any current, the relay becomes de-energized and gives the driver the « signal *on* » indication. If, on the other hand, the signal is *off,* the relay circuit is still broken by the displacement of the brush, but the ramp is alive, the brush picks up current, and this current keeps the relay energized, so that the driver does not get the *on* indication.

This system, used in Great Britain on most of the main lines of the Great Western Railway, where it gives very good results, is certainly superior to the preceding one. It is clear, in fact, that the *on* indication being given by the interruption of current, most of the possible failures are not against safety but only give the *on* indication needlessly. This would be so in the case of a broken battery or broken wire on the engine, of bad contact between brush and ramp of a broken signal wire of signal battery, etc...

e-4) Non-contact devices.

The only ones used by the railways which we are dealing with in this report (*) are electric, in which the *track* and the *engine* devices influence one another at a distance by induction. There are many types of this system (sometimes in France called « induction ramps »), and we cannot undertake to describe them here. They are to be found in service on several railways in the United States of America, and in Great Britain; others also are on trial on some French railways. They are certainly a good solution of the problem of signal repetition, for most of their possible failures are in the direction of

(*) To be more exact, the correct repetition of an *off* signal only gives an assurance that the greater part of the apparatus for repeating the *on* signals is working properly.

(*) Some other railways are using non-contact devices which make use of an *optical* connection between the signal and the engine. The devices designed by Dr. Bäseler, now being experimented with in Germany, are examples.

safety, and cause a wrong *danger* indication to be given on the engine. It should be noted, however, that some failures, in particular certain wire breakages or certain condenser failures make themselves apparent by the absence of any indication when passing a signal at danger, exactly as if there had been no signal at that point.

2. Continuous signal indication on the locomotives.

This equipment, called « cab signals » in America and « signaux d'abri » in France, are used on various railways in the U.S.A., particularly on the Pennsylvania Railroad. They are being installed in France (1936 summer) on the Caen-Cherbourg line of the State Railways. The Japanese Railways also have a section fitted with cab signalling.

The system is essentially different from that which we have just discussed under the heading of signal repetition. In that system the driver is given an indication when passing certain signals (*), often only the distant signal; in other words, such equipment helps the driver to observe certain signals when running past them, but actually give him no more information than he could get in its absence by simply observing the signals.

The cab signals which we will now proceed to examine constitute, on the contrary, a complete signalling system on the engine, under the following conditions.

They give as each signal is passed complete information as to the position of the signal at that moment, and in addition they give the driver *at each point on the track* information as to the state of the road ahead of him and consequently what he should do at that moment.

The indications given to the driver are the following: when the road is clear and the driver in consequence can continue to travel at high speed, a luminous indication of *line clear* — green lamp for example — permanently confronts him on his engine. If the train passes a distant signal showing the *on* aspect, the green light on the engine goes out and the « warning » indication — yellow light — takes its place, this change being accompanied by the blowing of a whistle to attract the driver's attention if he is not looking at the lamps at that moment. The yellow light in turn is replaced by a « proceed with caution » indication — red light — (the lighting up of which also causes a whistle to blow) if the train runs past a *stop and proceed* signal when *on*. But these lamps constitute not only a simple reminder of the last indication of the signal encountered, but also a complete system of signalling, capable of changing aspect at any moment in order to give the driver a more favourable or a more restrictive indication as the case may be. Thus for example, if an *on* signal clears after the train approaching it has passed the distant signal covering it, it is at the very moment of the *on* aspect changing to *off*, that the yellow light is changed to green on the engine, thus authorising the driver to resume full speed immediately. In the same way if a first train should run out of an automatic block section whilst a second train, having run past a *stop and proceed* signal is within that section, it is precisely at the moment when the first train leaves the section

(*) We do not, of course, consider as « continuous signalling » certain signal repeating devices of the types just examined, but in which the audible indication given to the driver when running past a signal is coupled with an optical indication existing on the engine up to the time of running past the signal. These equipments do not constitute continuous signalling, which by its very designation should be able to give a new indication at no matter what part of the road, but simply keeps in front of the driver an indication which can only vary when at a signal.

that the red lamp on the second is extinguised, authorising the driver to no longer *proceed with caution*, and is replaced either by the yellow light if the signal at the end of the section is *on* to protect the first train, or even by the green light if the signal at the exit from the section is *off*, for instance after the first train has left the main line for a siding.

Inversely, if a station is led, for any reason, to put the *stop* signal against a train, which has already run past the distant signal at *line clear* and is arriving in consequence at full speed, the green light on the engine of that train is replaced by the yellow light the instant the signal is put against the train. Similarly, it would be replaced by the red light if the road should become occupied ahead of the exit signal of the section.

The advantages of the system are evident. In the first instance it allows trains encountering any signal against them to reduce lost time to the minimum, since these trains are advised *immediately* they can accelerate. Inversely, it increases the safety factor to its maximum by giving the train a *reduce speed* or *proceed with caution* indication *at the precise moment* when it is necessary, even if the train has run past the signal which should normally have given this indication.

Usually the cab signal is supplemented by a vigilance recording device under conditions similar to those we met with the signal repeating systems.

Principle of the equipment.

Before installing cab signals, the line must be equipped with the automatic block and track circuits. It is then an easy matter to install cab signals. Figure 1 shows that as soon as a train enters a clear section, the track current, coming from the exit from that section, flows along one of the running rails until it reaches the first axles of the train, passes through these axles, and returns to its source by the other running rail. If, contrariwise, a train enters a section already occupied by another train, no current flows through the track circuit to its front axles. To sum up, current is present in the track in front of the train when it is in an unoccupied section, but is non existent when the section is occupied; it therefore will be sufficient for easily notifying the driver, to code the track circuit current and to pick it up by induction by means of a suitable device.

If the automatic block is the coded A. C. track circuit described on page 151/15, *no modification* is called for in the normal equipment of this block. It will be sufficient to install on the front of the engine, and slightly above each rail, a receiver coil, in which no current can develop if the engine is in an occupied section, but in which is produced on the contrary, by induction, a coded current of the same characteristics as the track-circuit current, either, in the example which we have taken, 180 impulses per minute when the section is clear and the signal ahead *off*, i. e. in a section which the driver has entered on a *line clear* signal being shown, and 75 impulses per minute when the section is clear but the signal ahead is *on*, i. e. a section which the driver has entered past a *stop and proceed signal* at *on*. The current, picked up on the engine, at 180 or 75 cycles, is evidently very weak, and, in the equipments in service it is habitually directed through a valve amplifier, before reaching the receiver (*). This equipment is, moreover, identical with that of figure 4; it comprises a relay which makes and breaks at the

(*) It is to be noted that it is possible to install a cab signal economically — trials in this direction are being made in France — by conveying the current picked up directly to neon lamps, which go out when the section is occupied, give 75 flashes per minute after a *warning* signal, and 180 per minute after a line clear signal.

frequency of the current picked up from the track, then two selector relays, the contacts of which light up in front of the driver aspects showing *stop, caution* or *line clear*.

If, contrariwise, the automatic block system is not coded, but of the classic type described on page 138/2 it will be necessary to modify this block by adding transmitters to code the track current suitably.

It is easy to see that this equipment provides integrally a continuous system of signalling upon the engine, keeping the driver advised at any moment of the state of the road. It is equally easy to see that the use of this apparatus gives a remarkable degree of security, of the same order as that which one can be credited to automatic block working itself. This results, in particular, from the fact that as in automatic block signalling, the failures which are most likely to occur (broken wires, loose terminals, etc...) result in needless *stop* or *slow down* indications, but never in a wrong line clear indication.

Finally, we may add that, with this system it is very easy to give the driver, in addition to the three indispensable indications (*line clear, caution, stop*) a fourth or *advance warning* indication, letting him know that the next signal he will meet is at *caution*. The addition of this fourth indication simply calls for three code transmitters instead of two, and three impulse frequencies. Thus, a large number of American railways use the frequencies 180 per minute for *line a clear*, 120 for *advance warning*, 80 for *warning — line occupied* corresponding to the absence of current, or to non-coded current. This fourth indication is precious in certain cases, especially on a line over which trains of very different types circulate, as for instance, suburban trains and express trains, of which the one type can be easily stopped within the length of a block section, whilst the others require a materially greater braking distance.

The working of cab signals is so satisfactory that certain railways in the U. S. A. completely rely on them, and have done away with all signals on the open road.

This elimination is not without its advantages. Quite apart from the question of economy, it facilitates drawing up working regulations, by doing away with every possibility of discordance between the aspects of the track signals and of the cab signals.

Against this, it is not entirely without drawbacks for instance, possibly it may diminish the attention which the driver should pay to the road. For one must not lose sight of the fact that other obstacles may present themselves besides trains (trees blown down, cattle on the track...) which do not cause the signals to operate, and it is desirable from the safety point of view that the driver shall be induced to look outside his cab. This difficulty can, of course, be got over, when the track signals are retained at the same time as the cab signals, by imposing on the driver an act of vigilance, recorded, before reaching a track signal at « caution » (*).

Besides, the elimination of the signals on the track gives rise to grave difficulty if the cab signal fails. If, for instance, a broken wire on the engine causes the cab signal to show the *danger* aspect permanently, and if the driver is incapable of repairing the damage immediately — and this is usually the case —

(*) It should be noted, however, that if the apparatus on the engine gives the driver the advance warning indication although this indication is not given by the signals on the track, this vigilance rule will be inoperative in compelling the driver to watch the road properly. It is, in fact, only after having seen on his engine, the *advance warning* indication, that the driver should expect to find on the track signal the *warning* indication, and consequently keep a watch on the road in order to be able to stop in good time.

there is nothing else to do but to ask for help or proceed *at sight* for the rest of the journey. Either solution upsets the traffic. If, on the other hand the signals are retained on the track, the driver can be satisfied with their indications, as if he had no cab signal.

Finally, it is evident that the elimination of the track signals entails the fitting of cab signals on *all* locomotives likely to run over the line.

After all, we are of the opinion that it is usually more advisable to retain the line signals, notwithstanding the installation of cab signals on the engines.

3. Comparison between repeater signals and continuous cab signalling.

Which of the two systems is preferable, repetition of the signals (it being understood that only the most modern systems are used, such as the induction ramp) or continuous signalling on the locomotives ?

This question is extremely complex, and it would appear to us indisputable, that, taking into account their previous equipment, their signalling schemes, and their financial resources, the railways may, *logically,* reach different conclusions.

At first sight, continuous cab signalling is superior to the repeater signals, first because it is safer in the event of a failure of apparatus, and secondly, because it provides maximum traffic facilities. Therefore, if a railway possessing neither one nor the other, should wish to improve its installations, and has considerable resources at its disposal, it should, in our opinion, adopt the system of continuous cab signalling. However, the fact should not be lost sight of that it is clearly reasonable to incur such heavy capital expenditure only for important lines carrying fast or dense traffic. Generally speaking, lines of this class are really the only ones to have sufficiently experienced maintenance staff required to ensure the proper working of the apparatus.

This view is, of course, theoretical, even for the important railways which we are interested in for the moment. But in practice it is not always possible to make a clean sweep of the past; there is the case, for instance, of a railway possessing relatively old repeater equipment on its locomotives. It is often quite reasonable to leave for the moment matters as they are, of course, making the best of the equipment in service. This is the case with the French main-line Railways which, as we have already stated, obtain good results with their ramps, and will certainly retain them for a long time on a great number of their lines, adding perhaps a few inexpensive detail improvements.

Besides, should a railway decide to equip the most important of the main lines with the quite modern apparatus, it should certainly study the question in relation to its other safety installations, and even to its schemes. It must not be forgotten that cab signals require in the first place the line to be equipped with the automatic block system, and track circuits. Their adoption is therefore specially suitable for lines already equipped, or about to be equipped, with automatic block. And one can well conceive that a railway wishing to improve the block system on its main lines, and resolved to instal the automatic block, will take care at the same time to fit continuous signalling on its locomotives, it being of course understood that the resulting heavy expenditure can be spread over a number of years according to financial resources. One can also very well imagine that another railway with manual block signalling with which it is satisfied and not proposing to instal the automatic block, will hesitate to incur the corresponding heavy expenditure required to equip its locomotives

with continuous signalling, and will prefer the induction ramp.

We may add here that various systems of signal repetition and continuous signalling are being worked out or are on trial, and the results should be taken into consideration by any railway called upon to come to a decision.

Specific conditions will consequently in each particular case lead to one or another solution of the problem. For, in examining this question, like all other safety questions, the real problem is to decide not what is the best that can be imagined, but simply how the available money can best be employed, taking into account the existing installations, the traffic conditions, and any other schemes under consideration.

4. Automatic application of the brakes (automatic train control).

Whatever steps may be taken (repetition of the signals, or continuous signalling) to *inform* the driver on his engine, these steps can be supplemented by an automatic application of the brakes to stop the train in case of failure on the driver's part.

Is this addition worth attention, and should it be adopted ? This question has given rise to many discussions, particularly at the last Session of the Congress held in Cairo, in 1933.

* * *

The problem of automatic application of the brakes is completely different according to whether it is applied at the absolute *stop* signals, or at the *stop and proceed* signals.

There is no difference of opinion as regards the application of the brakes at *absolute stop* signals, which normally may never be run past when *on*. If these signals are to be equipped with an automatic braking device, it must clearly be one which, at the moment the signal is run past, applies the brake, which the driver has no means of releasing before his train has come to a definite stop. Such an arrangement, which is easily installed, exists on various suburban lines where the trains run at relatively low speeds, and where a sudden automatic brake application in the event of an absolute stop signal being accidentally run past brings about a very rapid stop. Safety is therefore provided by such a system, in so far as the possible obstacle is not in the immediate vicinity of the signal.

On lines over which trains run at high speed, this system would be unsuitable, as for various reasons the *stop* signals have to be placed at a much shorter distance from the obstacle than the braking distance, safety being always assured by the use of a distant signal giving the aspect of the stop signal at a suitable distance therefrom.

It is always the *on* aspect of the distant signal which on main lines is notified to the driver by the signal repeating devices, or by continuous cab signalling, and for similar reasons it is within the vicinity of the distant signal that the automatic application of the brake should take place if need be.

A simple means of ensuring safety would be to apply the brakes at the distant signal when it is *on*, the driver being unable to release them before his train has come to a standstill. By definition the distant signal is always so located that an emergency application of the brake will bring the train to a standstill before reaching the stop signal, and consequently before the obstruction. Clearly this system would be inadmissible on account of the delays it would cause, as it often happens that on busy lines a train that runs past the distant signal at *on* may find the stop signal *off* and consequently have no need to pull up. It is therefore necessary to make the system somewhat less rigid. Two me-

thods can be employed, according to whether automatic braking is used, which is independent of the speed of the train, or on the contrary automatic braking dependent on the speed.

a) **Braking independent of the speed.**

In this system the driver can prevent the automatic application of the brake by operating an acknowledging device, either immediately before passing the *on* signal, or immediately after. In either case the operation of this device enables the driver to run his train at the exact speed he desires.

This system which is in use on various railways of the U. S. A. and Great Britain, does not prevent accidents with certainty as the driver, having seen the distant signal at danger, can perfectly well, after having cancelled the automatic brake application, run at too high speed, pass the stop signal, and collide with the obstruction beyond it.

In fact a certain number of accidents have occured under these conditions, chiefly because the drivers have wrongly thought that they would find the stop signal *off*. (It should be noted by the way that this mistake, possible with signal repeaters, would be extremely unlikely with continuous signalling, as with this latter system the driver is *always* informed of the aspect of the signal he is approaching).

It can definitely be stated that the only case in which the automatic brake application independent of the train speed gives additional safety as compared with repeater signals or with cab signals is when there is no one on the engine in a condition to apply the brake when passing a distant signal at danger. On large systems, where normally two men are on duty together on the engine, this case is *extremely unlikely*, and we do not think that automatic brake application independent of the train speed is to be recommended. It is, moreover, interesting to note that in the U. S. A., a country where automatic braking is much more developed, certain railways have given it up, often when installing continuous signalling on their engines.

b) **Braking, dependent on the train speed.**

The above system can be improved by automatically braking the train, and of course always to a stop, in the sole case where the driver exceeds the speed which he is under obligation to respect in the interest of safety.

Such apparatus, still little used, may vary a good deal. For instance the following plan is possible.

After passing the *on* distant signal, the driver should immediately prove his watchfulness by pressing a special button. If he does not do so, within 5 seconds for example, after passing the signal, the brakes are automatically applied and the train is stopped. If contrariwise, the driver acts in good time no braking action follows, but the speed of the train is controlled at several points on the road between the distant signal and the stop signal (naturally this speed control ceases immediately if the stop signal goes to line clear). At each of these points nothing happens if the driver has reduced the speed below that previously fixed for this type of train, but if he exceeds this speed the automatic brake is applied and stops the train. The German State Railways are now installing apparatus of this kind, but we will not say anything more about them as they will be dealt with in the report of our colleague, Mr. MISZKE.

What ought we to think of the automatic application of the brake dependent on the train speed ?

Like automatic braking independent of the train speed, it guarantees safety in the event of the simultaneous failure of

both men on the engine. But as we have already remarked, this event is so unlikely that it does not seem to justify such complicated and costly equipment.

On the other hand, unlike the *independent* system, the speed control guarantees safety in the case of a driver who having run past a distant signal at danger wrongly believes the stop signal is *off*. As we have already stated, this case is also extremely unlikely if the engine is equipped with cab signals, and we do not consider that it should be necessary as a rule to supplement cab signals by speed control.

There remains the case of engines not fitted with cab signals. Their equipment with automatic braking controlling the speed is certainly of some interest, but it should not be forgotten that on the one hand the equipment is complicated, and on the other that its failures, if they were frequent, would be very annoying on account of the needless stops they would cause. Therefore, as most of these systems have not been in service very long, it seems more prudent not to form any definite opinion until the results given by the apparatus have been closely followed, but to consider the question as one of those likely to occupy the attention of signal engineers for several more years.

* * *

In conclusion it should be noted that the question of the automatic brake application might change its aspect on account of the present rapid development of the traction units (electric locomotives and coaches, internal-combustion-engined locomotives or railcars, etc...) staffed by one man. The absence of a second man on the power unit leads in certain cases to the use of a device, the « dead man's handle », which stops the train in case of failure of the driver. The dead man's handle is, of course, nothing less than a device for automatically applying the brake, which could equally well be adopted, if need be, to the passing of signals at danger.

* * *

In the case of the railways to which we belong (we only speak for them, because we have seen how difficult it is to arrive at general conclusions) we think that *at the present time* it would be a mistake to go in for automatic brake application. The money at our disposal for signalling purposes (*) should, we think, be used for the time being for equipping our important lines with automatic block signals of the day colour-light type (this block being preferably so arranged that cab signalling could be added later) as well as modern power signalling installations, our ramp signal repeating equipment being retained for the time being. From the same point of view, part of this money should, if need be, be spent on centralised traffic control of certain very congested sections of line.

Only after the completion of a vast programme of automatic block signalling, modern power boxes, and centralised traffic control, should one proceed to the improvement of the signal repeating systems, by replacing on the main lines the existing ramps by the cab signal, in principle without the automatic brake application, it being understood, however, that possibly this feature — preferably dependent on the train speed — might be installed on certain very fast engines, particularly those driven by *one* man.

(*) A first question is, of course, to determine exactly how the total amount available for improving the safety equipment should be divided between signalling properly speaking, track renewals, improvements at level crossings, the construction of metal rolling stock, etc., etc.

[621. 392 & 625 .143]

INTERNATIONAL RAILWAY CONGRESS ASSOCIATION

13th SESSION (PARIS, 1937).

QUESTION II.

Use of welding :

1. to obtain extra-long rails;

2. in manufacturing and repairing points and crossings.

a) **Results obtained by using extra-long rails. Methods used to ensure safe expansion of the rails and anchoring of the track.**

b) **Technical and financial results shown by welding points and crossings.**

REPORT

(France and Colonies, Spain, Portugal and Colonies, Italy, Czechoslovakia, Bulgaria, Rumania, Jugoslavia, Greece, Turkey, Egypt),

by J. RIDET,

Ingénieur des Ponts et Chaussées, Ingénieur en chef adjoint de la Voie et des Travaux; Compagnie des Chemins de fer de l'Est (France).

Seventy-four Railways were consulted and the present report is based on the replies received from the undermentioned twelve :

Egyptian State.
French State.
Alsace-Lorraine.
French Est.
Paris-Orléans—Midi.
French Nord.
Paris-Lyon-Méditerranée.
Indo-China & Yunnan Railways.
Piedmontese Tramways Company (Italy).
Rumanian State.
Czechoslovak State.
Jugoslav State.

Eighteen Administrations acknowledged receipt of the detailed questionnaire sent them and asked to be excused from replying, either because they did not weld rail joints or points and crossings, or because they were still without sufficiently long experience. These Administrations were :

Bulgarian State.
Andalusian Railways (Spain).
Madrid-Saragossa-Alicante.
National Western of Spain.
Société Générale des Chemins de fer Economiques (France).
Algerian State.
Paris-Lyon-Méditerranée (Algerian Lines).

Gafsa (Tunis).
Tunisian Company.
Colonial Railways of French West Africa.
Djibouti—Addis-Abeba.
Réunion Isle.
Damas-Hamah and Extensions.
Portuguese Railways Co.
National Portuguese Railways Co.
Lourenço-Marquès.
Turkish State.
Cambrésis (France).

* * *

We wish to thank the Administrations who, by replying to the questionnaire and supplying the information at their disposal, have enabled us to complete this report.

* * *

CONTENTS :

* * *

CHAPTER A.

Review - Statistics - Generalities.

I. — General information.

Welding rails together end to end to do away with fish-plate joints, or at least reduce the number, has only come into extensive use on the railways recently, although it is some thirty years ago since it was first done.

The French Nord, in 1906, welded, for the first time, 28 joints by the thermit process at Saint-Ouen les Docks.

The weld was made by what is called he pressure method, then already in use on tramways.

As welding had not proved itself on railways the welded joints were fitted with bolted fish-plates like the ordinary oint. These welded rails were removed n 1935 on account of wear. Not a single joint had broken. The photograph, figure A. 1 shows one of these oints after 29 years' service.

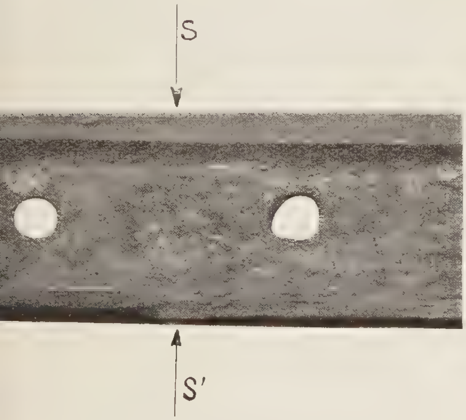


Fig. A. 1. — One of the 28 thermit welds laid in the track in 1906 on the French *Nord* — photographs taken after 29 years in service.

The irregular lines visible are not cracks, but the edges of highly oxidised areas, the joint having been photographed without being cleaned.

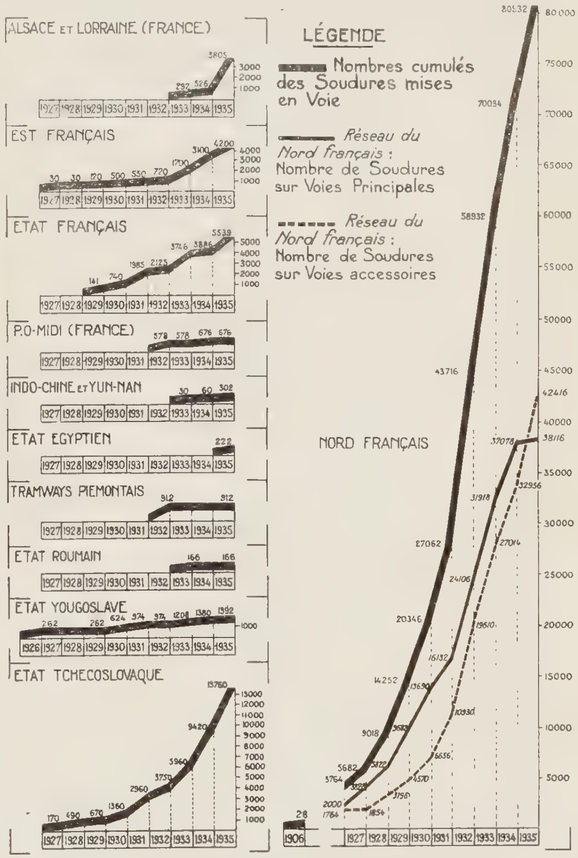
Note: SS' = location of the weld.

Further joints were made on the *French Nord* in 1909, 1912 and 1921. Subsequently welding came into general use on this railway, and today some 10 000 welds are made yearly. Most of the other French railways started to weld rail joints between 1927 and 1933.

The following 5 companies have in service a considerable number of welded joints :

Jugoslav State, starting from 1926.
Czechoslovak State, starting from 1927.
Piedmontese Tramways, starting from 1932.
Rumanian State, starting from 1933.
Egyptian State, starting from 1935.

The diagrams, figure A. 2, and the table A-*a* give statistics of the joints in use on the different railways at the 31st December 1935. Figure A. 2 shows that the railways have confidence in welded joints, as the number in use increases regularly.



Legend:

Sum total of welds in service.
French *Nord:* Number of welds in the running lines.
French *Nord:* Number of welds in sidings.

Fig. A. 2. — Diagram showing the number of welded joints in service on each railway system.

Table A-*a* shows that :

Most of the railways have put

TABLEAU A-*a*. — **Statisti**

			EGYPT. *Egyptian State.*	FRANCE A		
				Alsace-Lorraine.	*Est.*	*State.*
Running track	in tunnels.	Number of tunnels.		1	14	15
		Length of single track laid with welded rails, km. (*miles*).	...	1.6 (*1.0*)	14.6 (*9.1*)	38.2 (*23.7*)
		Length of rails welded into one bar, metres (*ft. in.*).	...	54 (*177' 2"*)	22, 36, 48, 54, 96 (*72' 2 1/8", 118 1 1/4", 157' 5 3/4", 177' 2"* and *314' 11 5/8"*)	36, 54, 60, 72 and (*118' 1 1/4, 177' 196' 10", 236' 2 1* and *354' 4"*)
		Axle-loads, metr. (*Engl.*) tons. Train speeds, km./h. (*m.p.h.*).	...	20 (*19.7*) 90 (*56*)	15 to 21 (*14.8* to *20.7*) 60 to 120 (*37.3* to *75*)	15, 18, 20 (*14.8, 17.7 and 19.* 80 to 120 (*50* to *75*)
		Date put into service.	...	1933	1927 to 1935)	1929 to 1935
	outside tunnels.	Total length of single track laid with welded rails, km. (*miles*).	2.0 (*1.24*)	33.3 (*20.7*)	28.8 (*17.9*)	9.725 (*6.04*)
		Length of new rails welded into one bar, metres (*ft. in.*).	36 1 000 (7) (*118' 1 1/4"*, (*3 280'*)	104 (1) (*341'*)	...	24 and 36 (*78' 9"* and *118' 1 1/*
		Length of re-used rails welded into one bar, metres (*ft. in.*).	...	21 and 27 (*68' 10"* and *88' 7"*)	From 9 to 22 (*29' 6 3/8"* to *72' 2 1/8"*)	...
		Axle-loads, metr. (*Engl.*) tons. Train speeds, km./h. (*m.p.h.*).	...	18 (*17.7*) 40 to 75 (*25* to *46.6*)	19 (*18.7*) 70 to 90 (*43.5* to *56*)	20 (*19.7*) 50 to 130 (*31* to *80.8*)
		Date put into service.	1935	1934-35	1932 to 1935	1930 to 1936
Parts of running lines which are lightly loaded or run over at low speeds, and sidings. (*Marshalling yards, sundry station equipment, depot lines, embedded track.*)		Total length of single track laid with welded rails, metres (*ft. in.*).	...	5.3 (*3.3*)	6.0 (*3.7*)	16.7 (*10.4*)
		Length of rails welded into one bar, metres (*ft. in.*).	...	54 and 60 (*177' 2"* and *196' 10"*)	Various lengths between 9 to 36 m. (*29' 6 3/8"* to *118' 1 1/4"*)	Various lengths between 30 to 77 (*98' 1 5/8"* to *252'* 282 m. (*925' 2"*) 2 000 m. (*6 561' 8"*)

(1) Rails laid on metal bridges.
(2) Welded rails in station track, between platforms and at level crossings (embedded track).
(3) 200-m. (656') rails are fitted with expansion devices.
(4) Grooved rails under hall (Cherbourg Harbour Station).
(5) Grooved rail in paved street (Havre Harbour).
(6) 90-m. (295' 3") rails are fitted with expansion devices.

velded rails.

NIES.			ITALY	RUMANIA	*CZECHOSLOVAKIA*	JUGOSLAVIA
Nord.	*P.O.-Midi.*	*Indo-china and Yunnan.*	*Piedmontese Tramways.*	*State.*	*State.*	*State.*
6	...	1 of 30 m. *(98' 5")*	...	1 of 975 m. *(3 209')*	18	8
9.2 *(5.7)*	...	0.048 *(0.08)*	...	0.975 *(3 209')*	16.0 *(10.0)*	6.4 *(4.0)*
44, 192 and 288 *18' 1 1/4", 3/4", 472' 5", 11 1/4"* and *944' 10")*	...	48 *(157' 5 3/4")*	...	975 and 981 *(3 209'* and *3 227' 6")*	23, 30, 37.5, 40, 45, 50, 60, 75, 90, 100 and 120 *(75' 5 1/4", 98' 1 5/8", 123' 1/4", 131' 2 3/4", 147' 7 3/4", 164' 1/2", 196' 10", 246' 3/4", 295' 3 1/2", 328' 1"* and *393' 8")*	24, 30, 60, 210, 280, 360, 600 and 1 200 *(78' 9", 98' 5 1/8", 196' 10" 688' 10", 918' 8", 1 181', 1 968' 6" and 3 937')*
19 to 22 *.7 to 21.7)* 30 to 120 *50 to 75)*	...	10.8 *(10.6)* 45 *(28)*	...	19 *(18.7)* 60 *(37.3)*	10 to 20 *(9.8 to 19.7)* 40 to 80 *(25 to 50)*	18 *(17.7)* 60 to 80 *(37.3 to 50.0)*
9 to 1935	...	1933 to 1935	...	1933	1928 to 1935	1931 to 1934
3.4 *(107.7)*	6.775 *(4.2)*	2.376 (1) *(1.47)*	6.15 *(3.8)*	0.18 *(0.12)*	107.8 *(67.1)*	7.9 *(4.9)*
(9)	...	48 (1) *(157' 5 3/4")*	...	36 *(118' 1 1/4")*	20 to 25 — 30, 36 50, 104 and 231 (1), 25 30 and 40 (2) *(65' 7 3/8" to 82' 1/4" — 98' 1 5/8", 118' 1 1/4", 164' 1/2", 341' 2 1/2", 757' 10 1/2"* (1), *82', 98' 1 5/8"* and *131' 2 3/4"* (2)	13.5, 22, 26 and 30 *(44' 3 1/2", 72' 2", 85' 3 5/8"* and *98' 5 1/8")*
22.6 (10) *' 2")* (10)	20 *(65' 7 3/8")*	...	13.5 (8) *(44' 3 1/2")* (8)	...	16, 22, 23, 24, 25 and 30 m. *(52' 6", 72' 2", 75' 5 1/4", 78' 9", 82' 1 1/4"* and *98' 1 5/8")* 23, 24 and 30 m. (2) *(75' 5 1/4", 78' 9"* and *98' 1 5/8")*	24 *(78' 9")*
13 to 22 *.8 to 21.7)* 0 to 120 *6 to 75)*	18.2 *(17.9)* 60 to 80 *(37.3 to 50)*	10.8 *(10.6)* 45 to 80 *(28 to 50)*	7 *(6.9)* 40 *(25)*	19 *(18.7)* 60 *(37.3)*	10 to 18 *(9.8 to 17.7)* 40 to 100 *(25 to 62)*	14.5 to 18 *(14.3 to 17.7)* 60 to 90 *(37.8 to 56)*
6 to 1935	1932 to 1934	1933 to 1935	1932	1933	1927 to 1935	1926 to 1934
.0 *(152.4)*	...	...	...	...	6.36 *(3.95)*	0.324 *(0.201)*
' 1") as a rule; 00-m. *(656' 2")* ails (3)	...	...	...	...	22 to 30 — 45, 60, 300 and 90 (6) *(72' 2" to 98' 5 1/8" — 147' 7 3/4", 196' 10", 984' 3" and 295' 3 3/8")* (6)	...

(7) 1 000-m. (3 280') rail lengths are fitted with expansion devices.
(8) 18-kgr. (36.3 lb. per yd.) rails.
(9) Outside tunnels, the French Nord only welded new rails on metal bridges. The lengths obtained by welding correspond to the parts of the bridges subjected to expansion. The greatest length thus welded is about 220 m. (721' 10").
(10) The most frequent length is 22.60 m. (74' 2").

welded rails into use in tunnels through which heavy fast trains are run. The single lengths much exceed that of the ordinary rails; the general run is 48 to 120 m. (157′ 5″ to 394′). On three railways, the French *Nord, Rumanian State* and *Jugoslav State,* the maximum lengths are 288, 981 and 1 200 m. (945′, 3 229′ and 3 937′) respectively;

— the French *Nord* and *Indo-China & Yunnan* Railways have laid welded rails of a continuous length of 220 and 48 m. (722′ and 157′ 6″) respectively on metal bridges;

— outside tunnels and bridges, extra long welded rails have been laid only by the *Egyptian State* Railways, who have laid one kilometre (0.62 mile) of track with the rails welded from end to end;

— in sidings, welded rails considerably longer than the standard lengths, and reaching 36 to 100 m. (118′ 1″ to 328′), have been laid by some companies. The French *Nord* and *Czechoslovak State* Railways have laid rails even as long as 200 m. (656′).

To sum up, extra-long rails are used, especially in tunnels (where the temperature variations are small) and sidings (because such lines are embedded in the ballast and the speed over them is low).

II. — Welding process.

1° *Thermit-pressure.* — Most of the rail welds have been made by the thermit-pressure method, with a piece of mild steel interposed between the two rail heads (as described in chapter B-1.I-1°).

This process has been applied in the most varied ways as regards, for example :

— the types of rails (44-55 kgr./m. = 88.7 to 110.9 lb. per yd. flat-footed (Vignole); 60 to 70 kgr./m. = 121 to 141 lb. per yd. grooved rails);

— the extent of wear (new rails, worn rails, and rails with ends cut off);

— the traffic carried (main lines run over by fast heavy trains with locomotives with up to 22-ton axle loads and speeds of 120 km. = 75 miles an hour; secondary lines with locomotives with 16 to 18-ton axle loads and speeds of 90 km. = 56 miles an hour; sidings worked over at low speed).

Details of these different cases will not be given, as the thermit-pressure method has now been standard practice for several years.

2. *Other methods* (thermit-fusion; electric butt — flash; electric arc; oxy-acetylene).

The number of welds made by processes other than thermit-pressure (thermit-fusion, butt-flash, electric arc, gas) is still relatively low. Most of the railways have used them and there is a tendency to extend their use, especially butt-flash welding. For this reason the following details of the welding done are given.

Egyptian State : 56 welded joints in a km. (0.62 mile) length laid with 36-m. (118′) rails, flash welded (see chapter B-1-II).

French Railways :

Alsace-Lorraine. — Thermit - fusion welded rails have been used on shunting sidings (see Chapter B-1.I-2°).

624 joints were made in this way in 1935, giving a total length of about 5 300 m. (3.3 miles). The existing rails (9 and 12 m. = 29′ 6″ and 39′ 4 1/2″ long) were welded together in the track itself. The 9-m. rails were welded in sixes to form 54-m. (177′ 2″) rails, and the 12-m. by fives to form 60-m. (196′ 10″) lengths.

Est. — 150 flash-welded joints were put into service in 1932 in the running track of branch lines (Vesoul to Gray and Neufchâteau to Toul) on which locomotives with 18.5-ton axle loads are used, and the speed is 90 km. (56 miles) an hour.

Recovered rails with the ends cut off have been welded in pairs into 16 and 22-m. (52′ 6″ and 72′ 2″) lengths; 200 joints have been made by the thermit-fusion process on similar rails in the running track of the Troyes-Sens secondary line, the locomotives having 18.5-ton axle loads and the speed being 75 km. (46.6 miles) an hour.

State. — Arc welding has been used in the harbour lines at Havre to join 60-kgr./m. (121 lb. per yd.) grooved rails with 38.75-kgr./m. (77.1 lb. per yd.) bull-headed rails.

Nord. — 12 joints were made in sidings by the thermit-fusion process, in 1923, as an experiment.

A further 90 similar joints were welded in 1927, and now the process is in general use in sidings, 31 664 welds having been made up to the end of 1935.

Since 1931, flash welding has been used alongside thermit welding, 10 000 such welds being in service at the end of 1935, 9 000 in sidings and 1 000 in running track.

Paris Orléans-Midi. — This Company has two sections of track with thermit-fusion welded joints.

The two sections are on main lines run over by locomotives with 18-ton axle loads at speeds of 80 and 60 km. (50 and 37.3 miles) an hour respectively.

The rails welded are re-used bull-headed rails weighing 42.54-kgr./m. (85.6 lb. per yd.) with the ends cut off, making the length 10 m. (32′ 9 3/4″). They are welded in pairs into 20-m. (65′ 7 1/2″) lengths.

578 joints were welded on the first section in 1932, and 98 on the second in 1934, by the same method, except that a steel plate hoop 10 mm. (3/8″) thick was fitted hot round the bottom heads of the bull-headed rails to be welded to hold them together.

Indo-China & Yunnan. — A few oxy-acetylene welded rail joints were made in 1935 in a running track as an experiment.

Czechoslovak State. — This system has in service, in different parts of its lines, the following welded joints :

92 — arc welded;
30 — oxy-acetylene welded;
54 — flash welded.

Jugoslav State. — 12 oxy-acetylene welded joints in a siding have been in service as a trial since 1935.

Piedmontese Tramways. — The 912 welded joints in service on these lines were all arc-welded.

* * *

CHAPTER B.

B-1. — Description of rail welding processes.

The processes most used to day are :

thermit,
electric (butt-flash welding).

Arc and oxy-acetylene welding are also used.

The thermit process is the one most widely used on the railways covered by this report, and was first applied in France, in 1906, on the *Nord Railway.*

Two methods are in use : pressure, and fusion. A detailed description is given after a brief account of their principle features.

1) *Pressure method.*

The characteristic feature of this method is the forging pressure exerted on the rails at the moment of welding; this process will therefore be referred to in this report as *thermit-pressure* welding.

The rail heads, after being heated by

the molten alumina released by the aluminium-thermit reaction, are forced together by a hand-operated press so that the rail ends become welded together without the addition of any molten metal. A piece of thin mild steel plate is interposed between the rail heads before beginning the operation. This plate is considered necessary when the hardness of the rail steel is above a certain value (corresponding to a tensile strength of 70 kgr./mm²=44.4 Engl. tons per sq. in.) Unlike what takes place when welding the heads, the foot and web of the rails are welded by the molten steel produced by the alumino-thermic reaction which provides the additional metal needed.

In pressure welding without interposition of a piece of plate steel between the rail heads, the web and foot are cut back with an oxy-acetylene burner so as to leave a gap of several millimetres between the rails at the web and foot, so that the rail heads remain in contact and can be pressure-welded, as described above.

2) *Fusion process.*

In this process molten steel is poured between the rail ends which are held a few millimetres apart. This space is filled and the rails covered over their whole surface near the joint with the molten steel which causes the rail ends to fuse and thereby weld together *without any forging pressure.*

This absence of forging pressure distinguishes this method from the previous one. This process is sometimes given the name of « intercalary weld » but the term is confusing as in both methods something is interposed, and will not be used in this report.

1. Thermit-pressure process.

The operations of welding by pressure in conjunction with the use of a piece of mild steel plate is described below. The process is well known, moreover, and is used by very many railways with few modifications.

a) *Preparatory work on the rail ends.*

The ends must be parallel and smooth so as to make good contact with the two sides of the piece of plate. They must also be clean and free from all traces of rust, grease, or moisture.

This work can be done by planing the two faces simultaneously by means of a hand-operated tool (fig. B. 1).

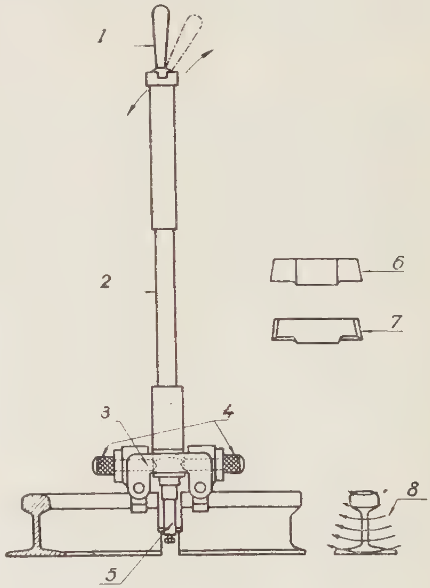


Fig. B. 1. — Thermit-pressure welding with inserted plate. Tool for cleaning up the rail ends to be welded.

Explanation :

1. Handle for working the lever and advancing the tool
2. Lever.
3. Support fastened to the rails.
4. Screw on which the lever is pivoted.
5. Tool carrier.
   Tool :
6. As seen from below.
7. Elevation.
8. Successive passes.

b) *Putting the piece of plate into position.*

A piece of mild steel plate 2 to 3 mm. (5/64″ to 1/8″) thick with parallel faces and slightly larger in section than the

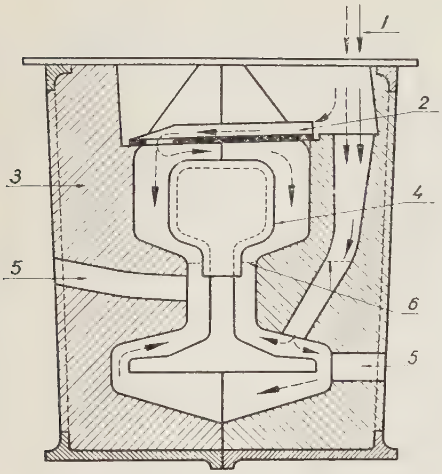


Fig. B. 2. — Thermit-pressure weld with plate Vertical and transverse section through the mould.

——— flow of the molten steel.
- - - - flow of the alumina.

Legend:

1. Flow of the steel and alumina produced by the thermit reaction.
2. Channel directing the alumina to the side away from the cast.
3. Mould.
4. Mild steel plate.
5. Vent.
6. Line of separation between the molten steel and the alumina.

rail head, extending half way down the web, is interposed between the two rail heads (fig. B. 2).

This plate is used to facilitate welding with both rails *pressed* together, thanks to the partial decarburization it gives rise to quite near the surface it is applied to.

The plate might have been extended down to the foot and pressure welding used throughout the rail section. It has been found preferable, however, for reasons of economy, to use the molten steel produced by the thermit reaction in the bottom half of the weld, and use fusion welding in this zone.

(When the plate is in position, the rails are brought into contact with it by means of a screw press (fig. B. 3).

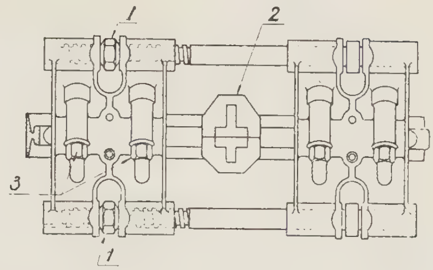


Fig. B. 3. — Thermit-pressure welds with inserted plate. Screw press for giving the forging pressure.

Legend:

1. Nuts for exerting the forging pressure.
2. Mould.
3. Nuts for tightening up the clips holding the press on the rail.

c) *Making and placing the mould.*

A two-piece mould in refractory clay, made in advance for each weld, is fitted round the joint to be welded and held in place by clamps (figs. B. 2 and B. 4).

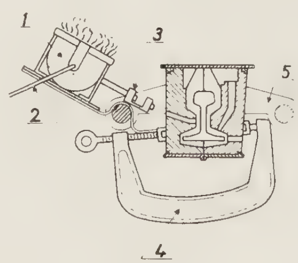


Fig. B. 4. — Thermit-pressure welding with plate. Mould in place ready for preheating the rails and for doing the welding.

Legend:

1. Wood charcoal heater.
2. Petrol supply.
3. Burner.
4. Clamps.
5. Press (fig. B. 3).

d) *Pre-heating.*

This operation is carried out for reasons of economy, and consists in heating the rail ends and drying out the mould by some cheap method. By doing

this the thermit reaction is called on to provide only the heat units needed to give the high temperature required for welding, as such units are the most costly.

As a rule a petrol blow lamp is used with the flame turned into the mould which then acts as a furnace. The mould is sheeted over and the heating continued for 25 to 30 minutes during which time the temperature of the rail ends can be raised from 700 to 800° C.

The burner is adjusted to give a reducing flame so as to prevent oxidation of the rail end faces which were machined in preparing them for welding. The reducing flame is found to remove any remaining traces of rust on the rails.

e) *Thermit reaction and pouring.*

The alumino-thermit mixture consists of iron oxide $Fe^2 O^3$ and aluminium in powder with the addition of other elements which will combine with the pure iron formed by the reduction of the iron oxide to convert it into steel of the desired composition.

The mixture is put into a metal crucible with a refractory magnesium oxide lining (fig. B. 5).

The reaction is started by igniting a charge on top of the alumino-thermit mixture. When the reaction is complete, the plug in the bottom of the crucible is removed. The molten steel, the denser, in the bottom, runs into the mould followed by the lighter alumina.

The steel and alumina remain separate in the mould, owing to the difference in density. The specifically heavier steel falls to the bottom of the mould, sufficient reactive powder being put in the crucible to fill the mould half

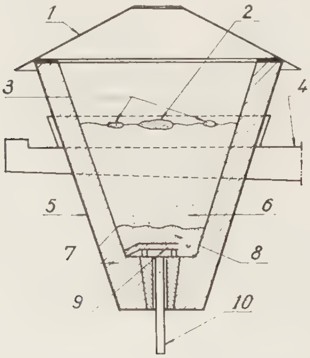


Fig. B. 5. — Thermit-pressure welding with plate. Crucible in which the thermit reaction takes place.

Legend:

1. Plate cover.
2. Lighting powder.
3. Additions which should mix with the molten steel.
4. Crucible support.
5. Plate crucible.
6. Thermit mixture.
7. Magnesium oxide lining.
8. Granular magnesium oxide.
9. Asbestos cover.
10. Tapping iron with large head.

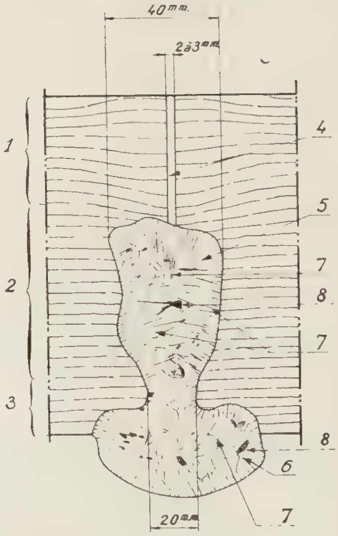


Fig. B. 6. — Vertical longitudinal diagrammatic section through a joint thermit-pressure welded with plate. (An intentionally badly made weld to show the casting defects).

Legend:

1. Rail head
2. Web of rail.
3. Foot of rail.
4. Mild steel plate welded by forging pressure.
5. Cast metal from the added metal and the melted rail.
6. Excess cast metal.
7. Dendrites.
8. Blow-holes.

way up the web of the rail with molten steel. This molten steel also fills the space between the rails which it melts for some 40 mm. (1 9/16″) along the web and some 20 mm. (25/32″) along the foot, thereby welding together these parts of the section. The excess metal forms a mass round the foot (fig. B. 6).

It may be asked what is the use of this excess metal and if it would not be cheaper to avoid it (less reactive mixture, with a smaller mould). If this economy were made, however, the quantity of heat given off would be too small. Besides in view of the inherent defects in cast steel, it is as well to have an excess of metal (figs. B. 6, B. 7 and D. 14).

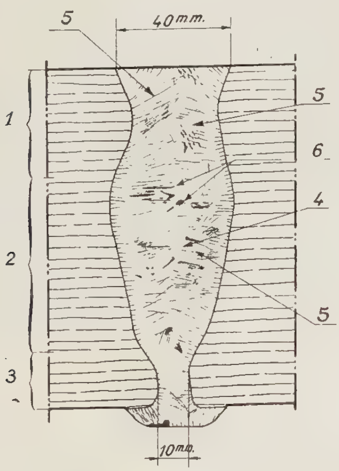


Fig. B. 7. — Vertical longitudinal diagrammatic section through a thermit-pressure welded joint. (An intentionally badly made weld to show the casting defects.)

Legend:

1. Rail head.
2. Web of rail.
3. Foot of rail.
4. Cast metal, from added metal and melted rail.
5. Dendrites.
6. Blow-holes and inclusions.

The alumina floats on the surface of the steel, surrounds the whole of the rail heads and brings them and the plate up to the welding temperature.

f) *Pressure.*

After 2 to 3 minutes the temperature of the rail ends is high enough for welding and the two rails are then forced together by means of the screw press. The weld is obtained by forcing the ends of the rails against the plate as in pressure forging. This pressure is an important factor in making the weld.

g) *Stripping.*

During cooling the metal contracts, which gradually reduces the pressure exerted by the screw press. As soon as there is no pressure, shown by it being possible to turn the nuts of the press by hand, the press is removed. At the end of 30 to 40 minutes the weld is cold enough to strip the mould. The solidified alumina is broken away.

h) *Annealing.*

The object of this operation is to improve the structure of the weld and the adjacent metal, and to eliminate certain defects inherent in cast steel (internal stresses, coarse grain, etc.). This will be dealt with in detail later on.

This annealing is still not current practice except on the French *Nord, Est* and *State,* but it is being done more and more.

i) *Restoring the running surface of the rail.*

The result of forcing the rails together is to cause a fin of metal round the joint. This fin is removed from the running surface of the rail with a chisel and then by grinding with a horizontal or preferably with a vertical spindle grinder. The work can also be done with a hand plane fitted with a milling cutter file.

The cast steel about the lower part of the rail is left untouched.

2. Thermit-fusion welding.

The following is the method of operation :

a) *Preparation of the ends to be welded.*

Unlike in pressure welding there is

no need to clean and carefully level the faces of the rail ends as in the pressure process.

The ends are roughly cleaned with a metal brush to remove any rust, and the two running surfaces are very carefully lined up with a gap of 9 to 11 mm. (23/64" to 7/16") between the ends.

b) *The mould is then made and put in place.*

c) *The rail ends are heated up.*

d) *Thermit reaction and pouring.*

These operations are similar to those with the pressure process. There are however two differences :

The quantity of cast steel produced by the thermit reaction is larger as it has to fill the whole of the gap between the two rails, form a rib all round the joint, and even a header on the top of the joint. This dead head ensures the metal being sounder as the defective metal collects in principle in this header.

As the cast metal forms an insert between the two rails even on the running face, unlike the pressure process, the quality of the metal has to be improved by additions (silicon, manganese, chromium, etc...).

The molten alumina floats above the steel and prevents the cast steel in the mould from cooling too quickly.

The rails are not forced together at all so that no forging pressure is exerted.

Fig. B. 7 shows diagrammatically in section a joint welded by this process.

e) *Stripping.*

After about 7 minutes the mould is broken away and the header above the rail is cut off quickly whilst hot.

f) *Annealing.*

g) *Restoration of the running surface.*

These operations are the same as in the pressure process.

II. — Electric welding (flash-butt welding).

This process, as a result of several years' trial, is rapidly coming into general use.

The ends of the two rails, brought together, are raised to welding temperature by the electric arcs set up between them. The weld is made by compressing the two rails so that a forging pressure is exerted, a guarantee of good work.

This process differs from what is known as the short-circuit or resistance process generally used in spot welding metal roofs, motor car work, etc... The rails are not heated by the Joule effect. There is no short circuit and this is so true that the ends of the rail only come into contact at the end of the process, at the moment the forging pressure is being exerted, when the current can be cut off.

The resistance and short-circuit process was tried in the beginning but it was soon realised that it meant considerable energy with a very low heat efficiency. This is due to the fact that the whole part of the rail through which the current flows becomes heated, obviously quite uselessly, and a large part of the heat is taken away by the cooling water circulating round the clamps supplying the current.

To make this point clear, there are electric resistance welding machines which, to weld a point 6 to 8 mm. (1/4" to 5/16") in diameter in two 1-mm. (3/64") plates have a power of 60 kVa, whereas the machines for butt-flash welding rails over an area of 6 000 mm^2 (9.3 sq. in.) have a power of only 400 kVa.

Flash welding involves the use of a machine on which the two rails to be welded are fastened. The frame of the machine is very rigid and carries two trolleys sliding longitudinally on it.

Each trolley carries a clamp, which

can hold the rails to be welded stationary, connected to the terminals of a single-phase electric transformer of up to 400 kVa. One of these trolleys can be moved by hand or automatically to give the to and fro movement mentioned below, required when starting to make the weld. The other trolley is operated by a press which puts on the rails the forging pressure required at the end of the welding operation.

Figure B. 8 illustrates a welding machine of French manufacture used, for example, on the French *Nord*.

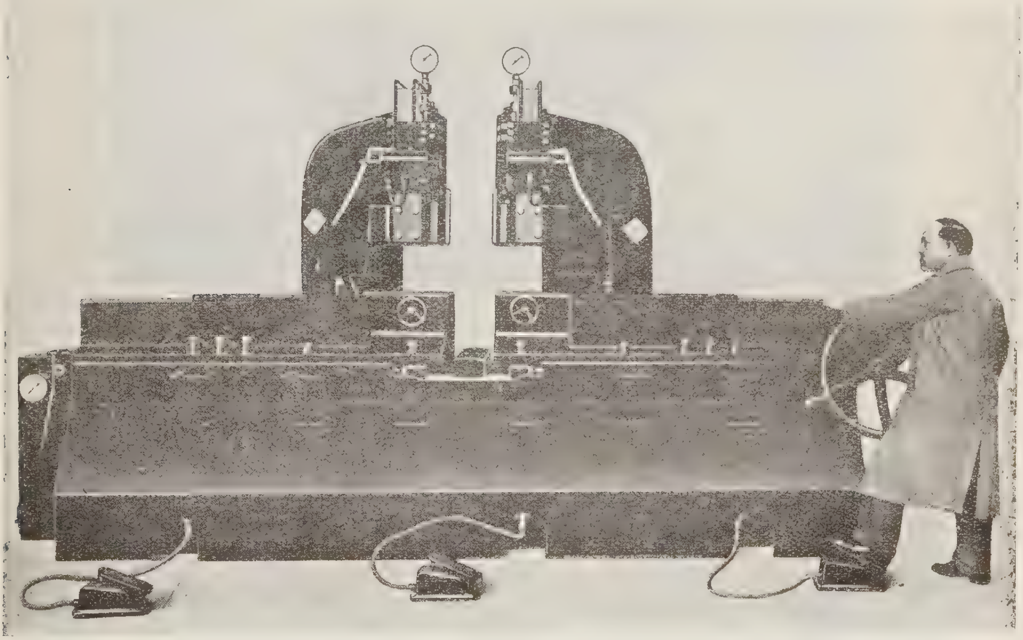


Fig. B. 8. — Semi-automatic electric flash welding machine.

The welding involves the following operations :

a) *Preparation of the rail ends to be welded.*

The surface of the rails is cleaned up by a portable grinder at the points the clamps of the machine will be applied in order to get good contacts. The end faces of the rail need not be cleaned up so perfectly as in the case of thermit-pressure welding. It does not matter if these faces are even covered with a thin skin of rust.

When recovered rails are being used, they are first of all straightened cold if necessary, and then sorted into pairs so as to weld together only rails worn to the same, or about the same extent.

The rails are very carefully lined up, an operation which is made easier by having straightened them beforehand, and are held in this position by means of screw clamps in which they can be handled without upsetting the alignment (fig. B. 8*bis*) and are then fixed on the welding machine.

b) *Preheating by flashing.*

The rails are brought almost into contact and then slowly separated.

Arcs flow between the nearest points.

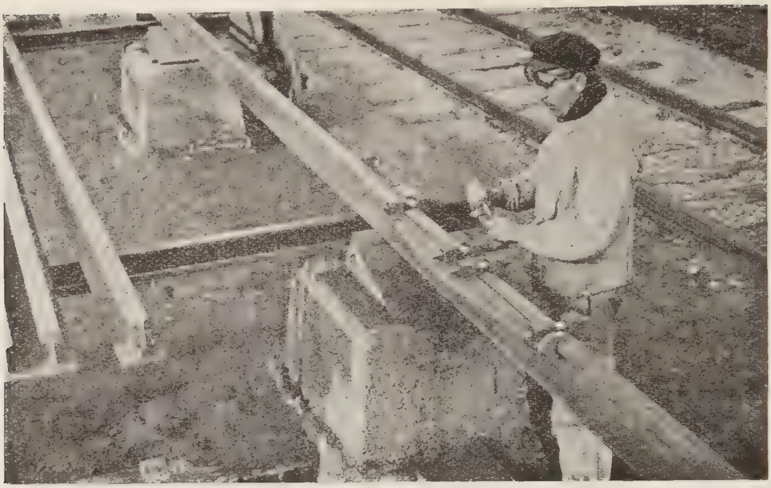


Fig. B. 8 *bis*. — Electric flash welding.
Screw clamp for holding in line the two rails to be welded and for retaining them in this position before they are put into the welding machine

The metal becomes very hot at these points and even burns with a projection of sparks through the magnetic effect of the burnt particles. The heat localised at the places where the arcs have formed is transmitted to the whole section of the rails, the temperature of which rises as it equalises through them.

The operation of bringing the rails together and then separating them for some 3 minutes is repeated. During this time of preheating some 4 mm. (5/32″) of metal is burnt away.

c) *Final flashing.*

During this period, which is much shorter than the previous one, as it can only last 4 to 5 seconds, the metal burnt by flashing sometimes amounts to 10 mm. (3/8″), a large quantity. The faces of the two rails are thoroughly cleaned by these projections and no particles of oxide remain. In this way the metal is quickly and economically brought up to a white welding heat.

d) *The actual welding.*

The weld is then made as under a forging press.

The compression can be 5 to 6 kgr./mm^2 (3.8 Engl. tons per sq. in.) of the rail section, i.e. 30 ton 35 tons in the case of 46-kgr./m. (92.7 lb. per yd.) rails.

The pressure gathers the metal which equals a forging operation and welds the rails over the whole section. A fin forms round the welded joint.

The welding is therefore obtained by pressure forging over the whole rail section, which distinguishes it from the thermit process in which, with the pressure method, the forging action only takes place on the top section of the welded rails.

e) *Cooling.*

As soon as the pressure has been exerted on the joint, the current could be cut off, but it is usual to keep it on for about a minute to prevent any brittleness due to sudden cooling.

The electrical resistance between the clamps of the machine is less than during the flashing period and the current increases, though limited by the fall in voltage in the transformer. The quan-

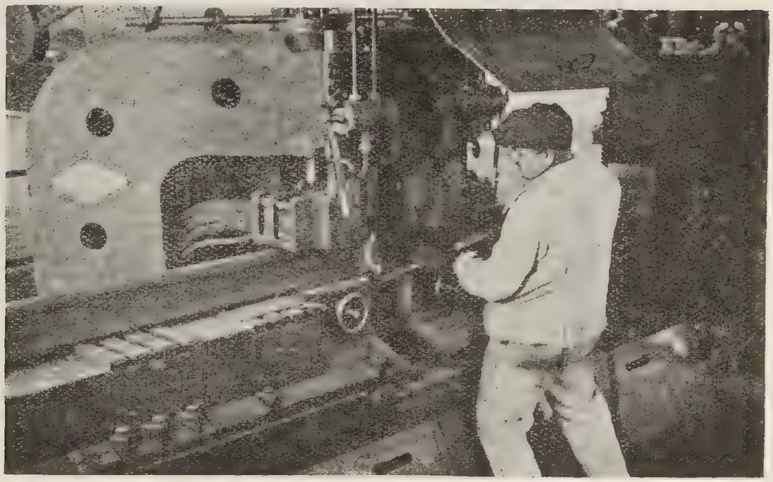


Fig. B. 8 *ter*. — Electric flash welding.
Removing the fin after welding by means of a pneumatic hammer.

tity of energy converted into heat in the vicinity of the weld is much less than in the flashing period, so that this part cools off slightly whilst the adjacent areas become hotter by thermic conduction as well as by the Joule effect.

f) *Fettling.*

Whilst cooling down on the machine with the current still on, the welding fin about the joint is cut away with a pneumatic chisel (fig. B. 8*ter*). This fin need not be removed completely but only where cross hatched in figure B. 9, so as to remove the hollow line marked 2 on this figure, which might start a crack.

g) *Restoring the running surface.*

When the temperature of the welded joint has fallen sufficiently, the current is cut off and the rail removed from the machine. The running surface is smoothed off by a high-speed (6-7 000 r.p.m.) revolving cutter which machines the surface whilst it is still red hot (fig. B. 9*bis*).

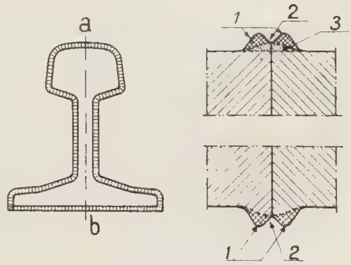


Fig. B. 9. — Electric flash welding. Dead head produced by the forging pressure.

Legend:

1. Part to be cut away hot with a chisel.
2. Hollow, liable to start a crack if the parts marked 1 were left.
3. Excess metal to be ground off after chipping off the other parts.

The section *a-b* is to a larger scale than the cross section. In both figures the size of the dead head has been exaggerated on purpose.

Automatic welding.

Non-, semi-, and fully automatic welding machines are on the market.

In the *non-automatic* machines, the operator controls the whole of the welding operations.

Fig. B. 9 *bis*. — Electric flash welding.
Grinding the running surface after welding.

The repeated movements of bringing together and then separating the rails during the preheating and final flashing periods are hand operated by means of a hand wheel. The operator learns the rhythm of the operations by experience. He has to be careful not to leave the rails in contact so as to save current and prevent premature welds at a few points of the rail ends. They should not be left separated too long as this would cool the rail ends.

When the operator thinks the whole of the rail ends have reached the welding temperature, he starts the hydraulic press to compress the rails.

In the *semi-automatic* machines the alternating movements are also hand-controlled, but the compression movement is automatically applied as soon as the rails have been shortened by a predetermined amount (a total of 12 to 14 mm. = 3/8″ to 9/16″) for example, ascertained by experiment for the sections to be welded.

In the *automatic* machines, once the rails are fastened in place by pressing a starter button, the weld is done automatically without the operator interfering. The to and fro movement is controlled by a motor and the compression is applied as soon as the rails have been shortened a predetermined amount by the flashing.

Comparison between thermit and electric flash welding.

The thermit process requires little equipment, the cost of which can be distributed over a few welds; it can be used in a shop or yard near the track or on the track itself, in the case of sidings on which the train workings can be suspended, and provided the fusion process be used. It is the most economical process when only a few joints are to be made at a given point.

The electric process is much cheaper than the thermit process providing the relatively high cost of the machine and the auxiliaries (generator, transformer, etc.) can be spread over a sufficient number of welds, say 10 thousand.

Although in many of the present installations with electric welding machines the rails are welded in a shop, a transportable equipment, a sort of travelling shop, for use anywhere on the railway to weld rails in the track or near where they are to be laid can be imagined. Such a travelling equipment could be fitted with diesel engines for generating the current.

In such a case the welds would have to bear the cost of sending the travelling shop to the place of use.

Finally electric flash welding is only applicable to rails of identical section or nearly so, whereas the thermit process, especially the fusion, can be used to unite rails of fairly different sections.

Thermit welding. Comparison between the pressure and fusion processes.

In the fusion process the running surface at the weld is formed of cast metal having properties differing from those of the rail metal. This lack of homogeneity can result in premature wear by crushing. To prevent this, the strength of the cast metal is raised by addition of special metals.

As regards the drop test, the results are much the same with either pressure or fusion welding, as will be seen by referring to table D-4 in chapter D.

This table also shows the value of annealing.

Electric welding. Comparison between the different machines.

With *non-automatic* machines there is a danger of starting to compress the joint before the rails have reached a high enough temperature throughout their section.

The *semi-automatic* machines reduce this risk very much, and meet most requirements. The quality of the welds is almost independent of the skill of the operator.

The *automatic* machines are best when a large number of similar welds are required. The specialised labour required with the other machines is not needed when the machine is accurately adjusted, the output can be increased and the cost more quickly amortized.

* * *

III. — Arc and oxy-acetylene welding.

These processes have been used experimentally to weld a few joints.

Such joints practically always include special parts welded to the two ends of the rails, such as tie plates, bearing plates, etc... These joints we will describe later on under the name « *complex joints* ».

As the technique of these methods is the same as in other industrial applications, it will not be described.

* * *

B-2. — Complex joints.

An endeavour has been made to strengthen the welded joint by the addition of metal details welded or not, such as fish-plates with or without bolts, tie plates, bearing plates, etc...

These « complex joints » are not widely used and only as isolated experiments.

The earliest on the railways consulted was on the French *Nord* when 28 welded joints were made in 1906.

The fish-plates and bolts as used in the ordinary joints were retained, as a precaution and not to strengthen the joint. These fish-plates, however, contributed to some extent in the reduction of the stresses set up in the welds by the passing loads. This is why we class these joints in the category of com-

plex joints. No breakage having occurred, subsequent joints had no fish-plates.

The *P. O.-Midi* in 1934 welded a number of joints by the thermit fusion process, with a steel hoop put in position hot, which grips the bottom head of the two rails to be welded together (bull-headed rails) as shown in fig. B. 10.

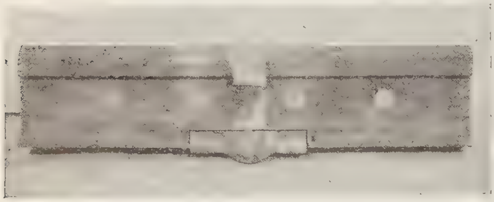


Fig. B. 10. — Thermit-fusion welding after fastening a hoop round the foot of the rail. (On the bottom head in the case of bull-headed rails.)

About a hundred joints were made on a line over which the locomotive axle load is limited to 18 tons and the maximum speed to 60 km. (37.3 miles) an hour (*P. O.-Midi* Rys).

When welding grooved rails the French *State* has adopted the same sort

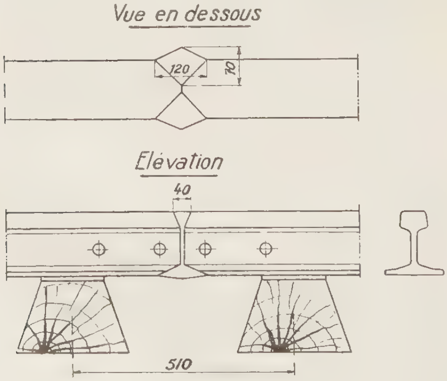


Fig. B. 11. — « Böhler » type welded joint (*Jugoslav State.*)

Note : Vue en dessous = view from below.

of arrangement with a metal tie plate under both rails.

For trial purposes the *Jugoslav State* Railways have welded, in sidings, six rail joints of the Böhler type (fig. B. 11) and six as shown in fig. B. 12.

In these designs the ends of the rails are bevelled off and then welded by the oxy-acetylene flame. In the joint shown in figure B. 12 a steel tie plate 8 mm. (5/16″) thick has been welded,

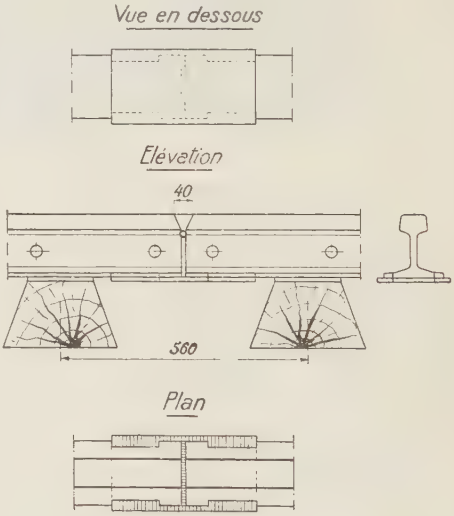


Fig. B. 12. — Welded joint. (*Jugoslav State.*)

in addition, under the rails close to the joint.

The *Czechoslovak State* Railways report that since 1933 they have had in service 92 arc-welded joints with a spe-

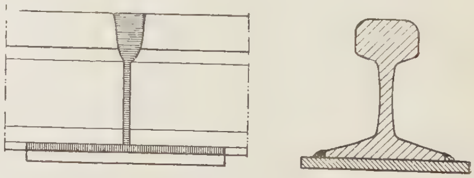


Fig. B. 13. — Electric-arc welded joint. (*Czechoslovak State.*)

cial steel tie plate under the rails as shown in fig. B. 13.

The *Piedmontese Tramways* have had in service, since 1932, 900 arc-welded joints of a similar design. The rails weigh 26 kgr./m. (52.1 lb. per yd.); the axle load is 7 tons, and the speed 40 km. (25 miles) an hour (fig. B. 14).

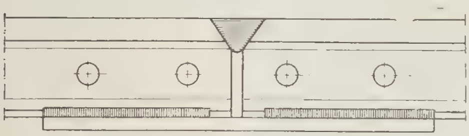


Fig. B. 14. — Electric-arc welded joint. (*Piedmontese Tramways.*)

The experience available with thermit and electric welded joints shows that additional parts are unnecessary.

* * *

CHAPTER C.

Defects in welded rails.

I. — Breakages.

Some breakages have been reported in joints welded by the old processes, i.e. not annealed (see table below). It appears that with the improvements now being made in the art of welding, and in particular annealing and in certain cases hardening and tempering in the parts adjacent to the weld, there is much less fear of breakage.

ADMINISTRATIONS. (1)		Total number of welded joints in service. (2)	Number of breakages reported. (3)
Egyptian State Rys.		222	0
France	*Alsace-Lorraine*	3 805	0
	Est	4 200	6
	State Rys.	5 539	8
	Nord	80 532	20
	P.O.-Midi	676	0
	Indo-China and Yunnan Rys.	302	0
Italy : Piedmontese Tramways		912	30
Rumanian State		166	12
Czechoslovak State		13 760	3
Jugoslav State		1 392	2

Five of the six breakages on the French *Est,* in column 3, were thermit-pressure welds (figs. C. 1 and C. 2). Their particular feature is the breaking away of the mild steel plate interposed between the rails. The breakage occurred after 7 days to 5 years service. The sixth failure occurred after 6 months and was of a flash-welded joint.

All the eight breakages on the French *State* occurred in the first length of welded rails laid in 1929. The rails were new and weighed 55 kgr./m. (110.9 lb. per yd.); they were drilled for fish-

Fig. C. 1. — Broken thermit-pressure joint (with inserted plate), subsequent to the plate breaking away. (French *Est.*)

plate bolts. The welds were made by the thermit-pressure method. The rails did not break through completely, but cracks developed in the web close to the weld. Some of the cracks extended to the bolt holes (fig. C. 3).

Laboratory tests carried out by the *State* Railways showed small cavities round these breakages, in the part where the metal had melted during the process, and a very marked dendritic structure was revealed.

A micrographical test showed that the rail steel was much coarse-grained, due to overheating in the part round the melted metal.

The *State* Railways came to the conclusion that the breakages were due to the absence of annealing after welding, and decided that henceforth all thermit welds were to be annealed.

Of the 20 breakages on the French *Nord,* one occurred with a thermit-pressure weld after 3 months service; thirteen with thermit-fusion welds in sidings during the first winter in service (these were made by inexperienced welders who had not pre-heated the rail ends sufficiently). Four electric welds broke in the first month in service.

The 30 breakages reported by the *Piedmontese Tramways* occurred during the first three months service. The failures were ascribed to defective welding; the welds were electric arc.

The 12 breakages on the *Rumanian State* Railways occurred after 6 months to 2 years service. Only 3 were due to the weld. The cause is ascribed to the alteration in the structure of the rail steel due to the heat during welding (thermit-pressure process).

The 3 breakages on the *Czechoslovak State* Railways occurred in thermit-pressure welds. Two breakages (in 1934) are ascribed to defective welding. They

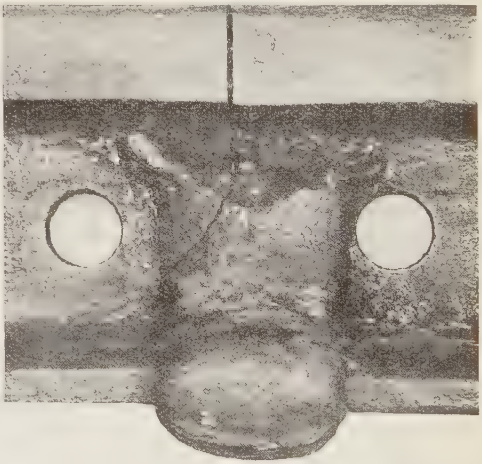


Fig. C. 2. — Crack in a thermit-pressure weld (with inserted plate). (French *Est.*)

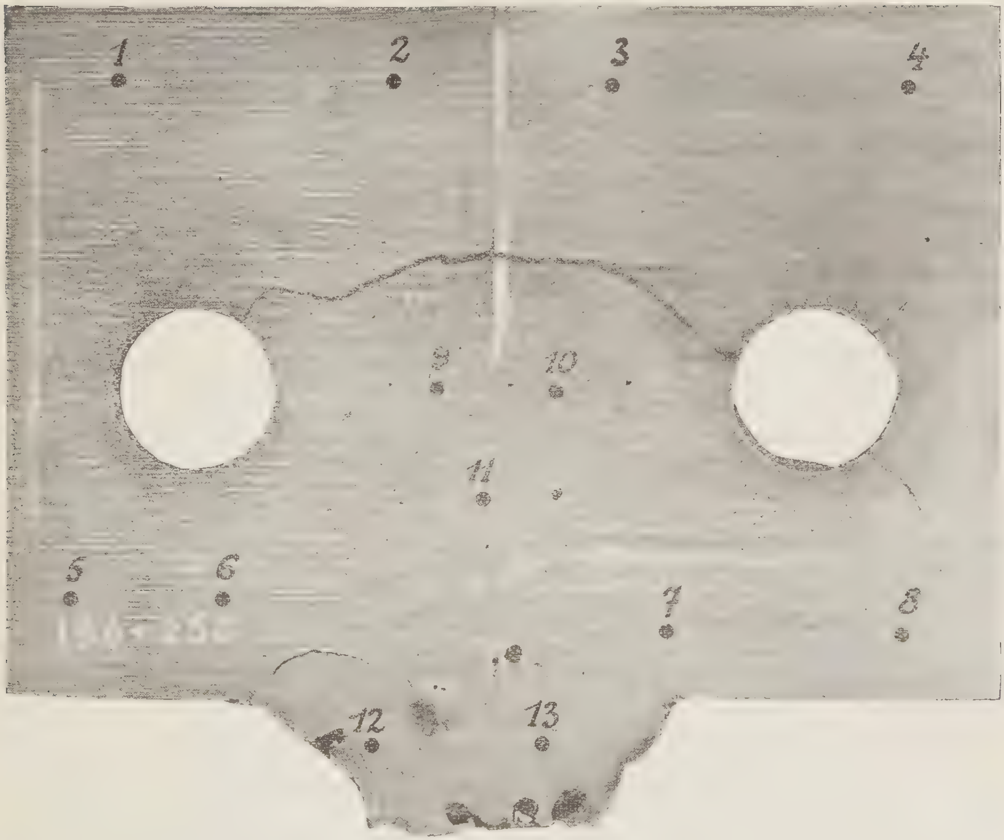


Fig. C. 3. — Thermit-pressure weld with plate.
Macrograph after etching by the « Fry » method (*French State*).

Brinell hardness tests.

Position . . .	1	2	3	4	5	6	7	8	9	10	11	12	13
Hardness number	196	228	196	179	212	196	196	196	159	153	149	153	146
Tensile strength, kgr./mm² . .	67	78	67	61	72	67	67	67	54	52	51	52	50
(Engl. tons per sq. in) . . .	*(42.5)*	*(49.5)*	*(42.5)*	*(38.7)*	*(45.7)*	*(42.5)*	*(42.5)*	*(42.5)*	*(34.3)*	*(33.0)*	*(32.5)*	*(33.0)*	*(31.6)*

occurred the day the rails were put into service, the mild steel plate inserted between the rail heads having broken away. The third breakage occurred 20 months after the rails were put into service.

The broken welds have not caused accidents as a rule, the reason being

that the rail has not broken at a number of places at the same time so that no part of the track has broken right away.

As a rule the welded joints are not specially watched, but are examined by the platelayers in the normal course of their duties.

The Railways are taking steps to reduce the number of breakages by special supervision during the welding operations and are endeavouring to improve the weld by suitable heat treatment.

The number of breakages, which is small relatively to the total number of welded joints, has not hindered the development of welding as is shown by Table A-*a* and the diagrams of figure A. 12.

Most of the breakages mentioned above occurred in thermit-pressure welds. which does not mean that this process is less reliable than the others, in particular than thermit-fusion. As mentioned above, pressure-welding is by far the most used method; it is used almost exclusively in the running roads, carrying heavy and fast traffic, whereas fusion is only employed in sidings where the joints are much less stressed.

II. — Formation of a hollow place in the weld of worn work-hardened rails.

When worn rails have been welded after cutting away the ends, a marked hollow place sometimes develops near the joint over a length of 0.60 to 0.80 m. (2′ to 2′ 7″).

This hollow appears after 10 to 15 days service. It then gradually deepens during some weeks up to a maximum depth of 1 to 2 mm. (3/64″ to 3/32″) measured with a 1-m. (3′ 3 3/8″) straight rule, laid on the rail. The edges of the hollow place having very little incline, no shock occurs, and the effect is the same as if the sleepers had given under the train.

The formation of these hollows is due to the surface of worn rails being work-hardened. The heat from the weld removes this work-hardening so that the rails are not so hard near the joint, and are gradually crushed down by the passing trains until the work-hardened condition is restored.

This very slight drawback has not interfered with the extended use of welding worn rails and can be avoided by hardening the surface of the rail near the joints by two jets of water gradually approaching the rail joint and one another.

The object of this process is to uniformly harden the whole area heated during the welding operation. The ends of the zone are colder than the centre part and tend to cool off rapidly, since the adjacent parts of the rail are cold. If then the whole welded area were hardened at the same time, or if the hardening were started at the centre, this position would undergo a much more serious treatment than the ends.

The tests already made of this method have been satisfactory and it is likely to be more widely used.

* * *

III. — High points on the running surface.

When the rails to be welded have not been properly lined up longitudinally and transversely, a high point sometimes occurs on the running surface at the weld (French *Nord, Alsace-Lorraine*). This defect is readily avoided if care be taken to ensure the rails being exactly in line before beginning to weld them.

If this defect develops, it can be removed as a rule by filing the high point off.

* * *

CHAPTER D.

D-1. — Tests and laboratory examination of welded joints.

Most of the railways have made me-

chanical tests and carried out laboratory investigations on rail joints welded by the different processes.

These tests and investigations included :

I. MECHANICAL TESTS.

1. Measurement of the surface hardness of welded rails;

2. Drop tests on lengths of welded rails;

3. Tensile and resilience tests on test pieces cut out of the welded rails;

4. Static bend tests on welded rails under a press;

5. Repeated alternating or ordinary bend (fatigue) tests on welded rails.

II. METALLOGRAPHIC EXAMINATIONS.

1. Macrographs;

2. Micrographs.

III. MAGNETIC SURFACE EXAMINATION.

IV. X-RAY EXAMINATION.

* * *

I. — Mechanical tests.

1. Measuring the surface hardness.

The surface hardness is measured at different points of the welded joints by the Brinell method.

Figure D. 1 shows as an example the results obtained with welded joints of old or new rails welded by the thermit-pressure, thermit-fusion, thermit-fusion with heat treatment, and electric processes.

This easily made test is used to make sure that the hardness of the weld and the metal adjacent thereto is slightly less than that of the rest of the rail.

Thanks to the heat treatment (hardening and annealing) surface hardness of the rail head is on the contrary, fairly the same at all points, as shown by the graph No. V of figure D. 1.

This test is very conclusive and shows how much the quality of the weld is improved by the heat treatment, which will be described later on.

Figure D. 2 shows the results of the Brinell tests on the longitudinal vertical section through a thermit-fusion weld.

2. Drop tests.

Drop tests have been made with short lengths of welded rails on the lines of those made when inspecting new rails.

The usual test on welded rails carried out by the French Railways is to drop a tup weighing 300 kgr. (660 lb.) on a welded section of rail 0.70 m. (2′ 3 1/2″) long carried on supports 0.50 m. (1′ 7 11/16″) apart. The height the tup is allowed to fall is not constant but increases regularly from 0.50 m. up to 4 m. (13′ 4 1/2″), after which it increases by 1 m. (3′ 3 3/8″) after each blow until the rail breaks.

Thus, when a weld breaks under a 6-m. (19′ 8 1/4″), blow it has stood 10 blows before doing so. Figures D. 3 to D. 3 VI are illustrations of welded rails after being so tested.

Table D. 4 gives some of the results of these tests. It shows that the welded joints annealed after welding give better drop tests than those not annealed.

The welded lengths, even when annealed, break as a rule more easily than the unwelded witness lengths. It must be admitted, however, that the results of the tests of the unwelded lengths usually vary considerably and that the inspection test results are often not as good as those in the table from the welded lengths.

The drop test is above all a method of investigation and comparison of the welds.

As the running surface is continuous when the joints are welded, the rails are not subjected at these points to shocks with the rail heads in tension, but only to alternating bending stresses like those

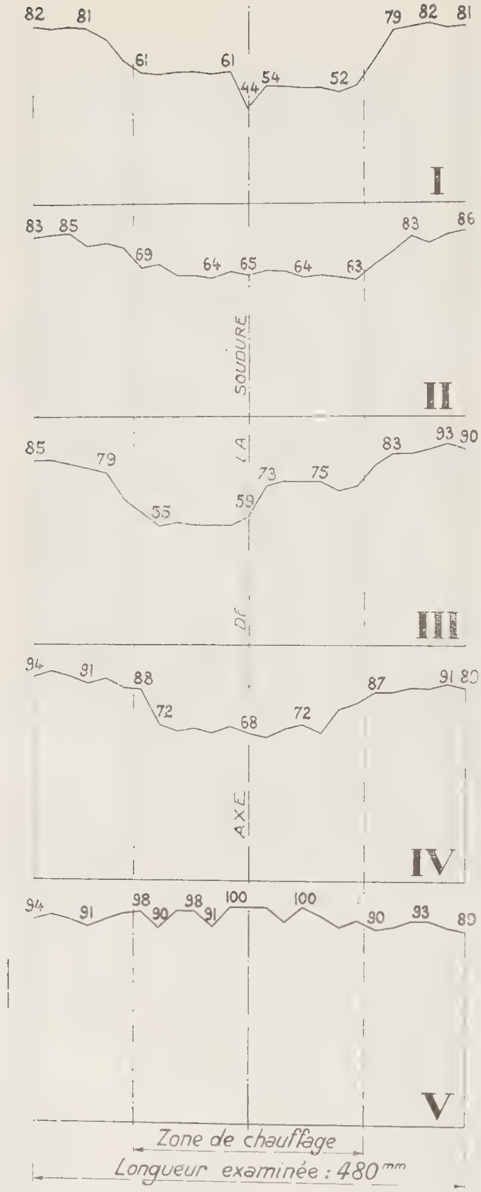


Fig. D. 1. — Examples of measurements of the surface hardness of welded rail joints.

The hardness is calculated from the diameter of the impressions made with a Brinell ball, spaced 20 mm. (25/32") apart on the longitudinal axis of the running surface of the rail. The Brinell numbers have been converted into the tensile strength in kgr./mm.² (1 kgr./mm.² = 0.635 ton/sq. in.).

Legend:

I. Thermit-pressure weld (old rails, work-hardened surface).
II. Thermit-fusion weld (old rails, work-hardened surface).
III. Electric flash weld (old rails, work-hardened surface).
IV. Thermit-fusion weld (new heat-treated rails. Weld *not followed* by heat treatment to restore its condition).
V. Thermit-fusion weld (new heat-treated rails. Weld *followed* by heat treatment).

Note: Axe de la soudure = centre line through the weld. — Zone de chauffage = heated section. — Longueur examinée = length examined.

developed in the body of the rail proper. For this reason a weld may behave satisfactorily in the track and yet not be so good under shock as the rail proper.

Good results under the drop test imply a minimum of internal defects and a very fine grain. It is therefore a positive indication of quality and a guarantee of good manufacture, besides reducing the anxiety of the railway engineers for the safety of the line, especially when new processes are in question.

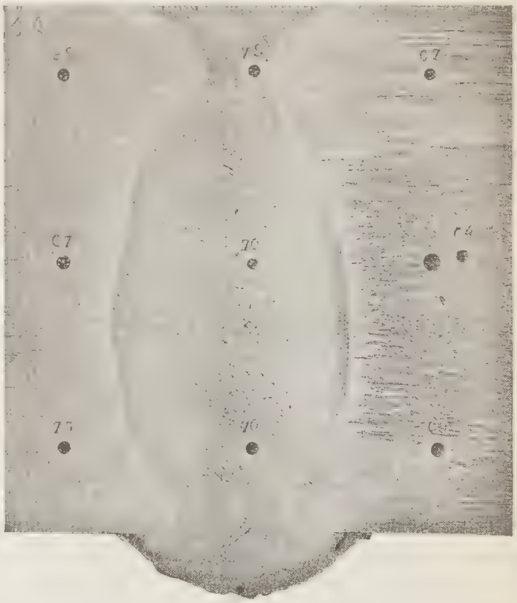


Fig. D. 2. — Thermit-fusion weld. Vertical longitudinal section showing the hardness in the two rails and in the added metal.

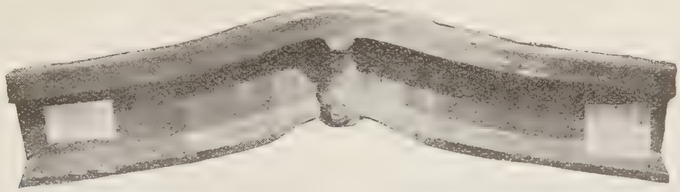


Fig. D. 3. — Thermit-fusion weld on standard French 55-kgr. (110.9 lb. per yd.) rails with the rail head hardened after rolling. The completed weld was heat-treated to restore in the rail head the hardened condition which the welding had destroyed.

The photograph was taken after 13 blows from a 300-kgr. (660 lb.) tup falling from heights increasing from 0.50 to 9 m. (1' 7 11/16" to 29' 6"). On continuing the test, the rail broke after the 17th blow from 13 m. (42' 8").

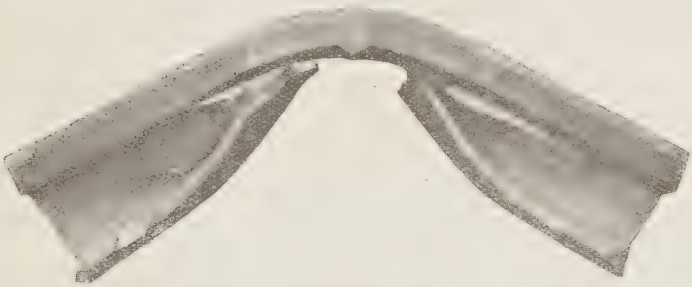


Fig. D. 3 *bis*. — Electric flash — butt welds on rails not heat — treated. The weld was annealed.

The photograph was taken after 14 blows from a 300-kgr. (660 lb.) tup falling from increasing heights from 0.50 to 10 m. (1' 7 11/16" to 32' 9").

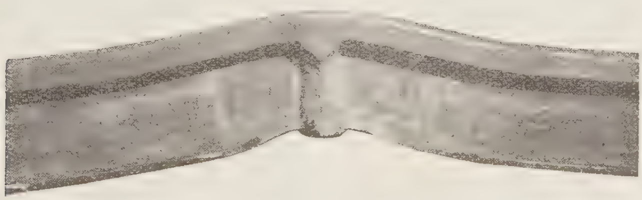


Fig. D. 3 *ter*. — Thermit-fusion weld on new French standard 46-kgr. (92.7 lb. per yd.) rails, the head of which was hardened after rolling The weld was annealed and heat-treated to restore the hardness in the rail head, removed by welding.

The photograph was taken after 13 blows from a 300-kgr. (660 lb. tup falling from heights increasing from 0.50 to 9 m. (1' 7 11/16" to 29' 6"). On continuing the test the rail broke at the 14th blow from 10 m. (32' 9").

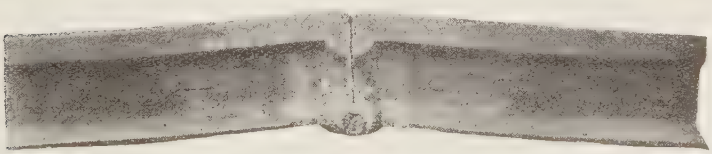


Fig. D. 3 IV. — Fusion-thermit weld on worn 46-kgr. (92.7 lb.) rails of the French Est type, not annealed after welding.

The photograph was taken after 9 blows from a 300-kgr. (660 lb.) tup falling from heights increasing from 0.50 to 5 m. (1' 7 11/16" to 16' 4 1/2").

TABLE D-4

Tests carried out on the French Est. — Weight of tup: 300 kgr. (660 lb

Welding process.		Height of drop causing breakage 3 m. (*9' 10 1/8"*) 4 m. (*13' 1*
		Reference test bars, unwelded.
I. Electric welding	1st series of tests	3 tests having given : 3 to 6 m. (*9' 10 1/8" to 19' 8"* Average : 4.35 m (*14' 3"*).
	2nd series of tests	3 tests having given : 3 and 4 m. (*9' 10 1/8" and 13' 1 1/2* Average : 3.50 m. (*11' 5 3/4"*).
II. Electric welding (other machine) .	1st series of tests	2 tests having given : 9 and 10 m. (*29' 6 3/8" and 32' 10* Average : 9.50 m. (*31' 2"*).
	2nd series of tests	2 tests having given : Not broken at 13 m. (*42' 7 3/8"*).
III. Thermit-pressure welding	1st series of tests	2 tests having given : 6 and 10 m. (*19' 8" and 32' 10'* Average : 8 m. (*26' 3"*).
	2nd series of tests	2 tests having given : 9 and 11 m. (*29' 6 3/8" and 36' 1'* Average : 10 m. (*32' 10"*).
	3rd series of tests	2 tests having given : 11 m. (*36' 1"*). Average : 11 m. (*36' 1"*).
IV. Thermit-fusion welding	1st series of tests	2 tests having given : 8 and 12 m. (*26' 3" and 39' 4 7/8* Average : 10 m. (*32' 10"*).
	2nd series of tests	2 tests having given : 12 m. (*39' 4 7/8"*). Average : 12 m. (*39' 4 7/8"*).

tests.

between supports: 0.50 m. (*1' 8"*). — **Rail set head below.**

e drops from: 0.50 m. (*1' 8"*). 1 m. (*3' 3 3/8"*) 1.50 m. (*4' 11"*) 2 m. (*6' 6 3/4"*) ' *4 7/8"*) 6 m. (*19' 8"*) 7 m. (*22' 11 9/16"*) 8 m. (*26' 3"*) 9 m. (*29' 6 3/8"*), etc.			Section of rails.
Unannealed welds.	Annealed welds.		
aving given: 5 to 7 m. (*16' 4 7/8" to 22' 11 9/16"*) Average: 6 m. (*19' 8"*).	11 tests having given: 3 to 11 m. (*9' 10 1/8" to 36' 2"*). Average: 7.10 m. (*23' 3 15/16"*).		Worn unhardened 46-kgr. (92.7 lb. per yd.). French Est rail.
having given: 1 to 10 m. (*3' 3 3/8" to 32' 10"*). Average: 5.25 m. (*17' 3"*).	...		
...	3 tests having given: 5 to 8 m. (*16' 4 7/8" to 26' 3"*). Average: 6.50 m. (*21' 4"*).		Do.
...	2 tests having given: 5 and 7 m. (*16' 4 7/8" and 22' 119/16"*). Average: 6 m. (*19' 8"*).		New unhardened 46-kgr. French standard rail.
having given: 1.50 to 2.50 m. (*4' 11" to 8' 2 1/2"*) Average: 2 m. (*6' 6 3/4"*).	3 tests having given: 2.50 to 3 m. (*8' 2 1/2" to 9' 10 1/8"*). Average: 3.50 m. (*11' 5 3/4"*).		Worn unhardened 46-kgr. French Est rail.
aving given: 2 to 2.50 m. (*6' 6 3/4" to 8' 2 1/2"*). Average: 2.17 m. (*7' 1 7/16"*).	3 tests having given: 2.50 to 3 m. (*8' 2 1/2" to 9' 10 1/8"*). Average: 2.83 m. (*9' 3 3/8"*).		New unhardened 46-kgr. French standard rail.
having given: 2.50 to 3 m. (*8' 2 1/2" to 9' 10 1/8"*) Average: 2.66 m. (*8' 8 3/16"*).	3 tests having given: 2 to 2.50 m. (*6' 6 3/4" to 8' 2 1/2"*) Average · 2.33 m. (*7' 7 3/4"*).		New 46-kgr. French standard rail, with head hardened after rolling.
having given: 3 to 5 m. (*9' 10 1/8" to 16' 4 7/8"*) Average: 4.33 m. (*14' 2 7/8"*).	3 tests having given: 9 to 10 m. (*29' 6 3/8" to 32' 10"*). Average: 9.33 m. (*30' 7 3/4"*).		New unhardened 46-kgr. French standard rail.
	Annealed after welding.	Head of rails rehardened after welding.	
having given: 2.50 m., 7 m. and 10 m. (*8' 2 1/2", 22' 11 9/16" and 32' 10"*). Average: 6.50 m. (*21' 4"*).	3 tests having given: 9, 11 and 13 m. (*29' 6 3/8", 36' 1" and 42' 7 3/8"*). Average: 11 m. (*36' 1"*).	3 tests having given: 12, 13 and 13 m. (*39' 4 7/8", 42' 7 3/8" and 42' 7 3/8"*) Average: 12.66 m. (*41' 6 1/2"*).	New 46-kgr. French standard rail, with head hardened after rolling.

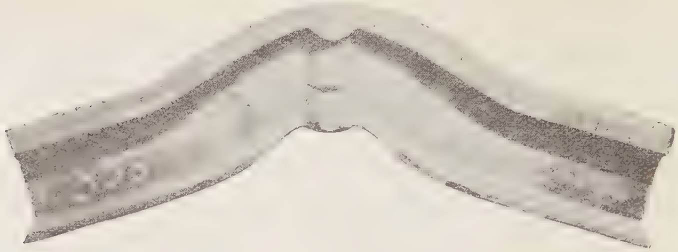


Fig. D. 3 V. — Thermit-fusion weld on new French standard 46-kgr. (92.7 lb.) rails, the head of which was hardened after rolling. The weld was heat-treated to restore the hardness in the rail head, destroyed by welding.

The photograph was taken after 17 blows of a 300-kgr. tup falling from heights increasing from 0.50 to 13 m. (1' 7 11/16" to 42' 8").
The test was stopped after the 3rd blow from 13 m., i. e. after the 19th blow from the start of the test.

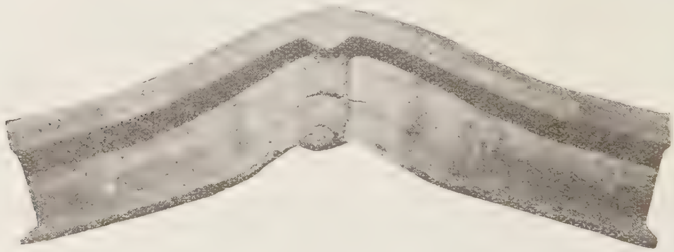


Fig. D. 3 VI. — Thermit-fusion weld on 46-kgr. (92.7 lb.) standard French rails, the head of which was hardened after rolling. The weld was annealed.

The photograph was taken after 15 blows from a 300-kgr. tup falling heights increasing from 0.50 m. to 11 m. (1' 7 11/16" to 36' 1").
On continuing the test, the rail broke at the 17th blow (from 13 metres).

The drop test therefore is still one of the best methods in investigating the welding of rails, and this is why the railways which investigate their welding results attach so much importance to it.

Breakages under the drop test cannot be compared easily, and to make the test more precise, attempts have been made to determine the energy absorbed at fracture by measuring the energy of the tup before and after the blow (which is easily done). This type of tup is called the « dynamometric tup ».

The difficulties in the way of making a practical testing machine have not been completely overcome, and such tests consequently have not come into general use.

3. Tensile and resilience tests.

Cylindrical test pieces have been cut from different parts of the welded joint to carry out resilience tests by the Charpy notched bar method [Mesnager test piece 10 × 10 × 55 mm. (3/8″ × 3/8″ × 2 3/16″) with a notch in the middle of the gauge length 2 mm. (3/32″) wide, 2 mm. (3/32″) deep, with the bottom rounded to a radius of 1 mm. (3/64″)].

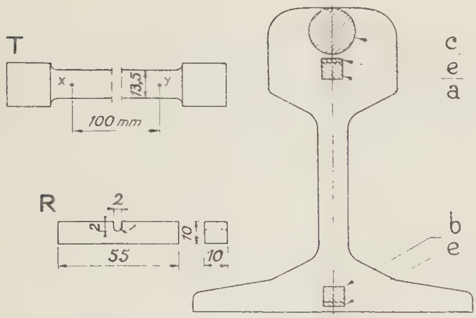


Fig. D. 6. — Position of the test bars used in the tensile and resilience tests.

Legend:

a-b Position of resilience test bars.
c Position of tensile test pieces.
e Position of notch in test pieces .
T Form of tensile test pieces (turned).
R Form of the resilience test pieces (parallelepipeds).

Table D-5 gives some results of such tests on thermit-pressure, and thermit-fusion welds, and on electric welds. Fig. D. 6 shows the positions from which the test pieces were cut.

4. Bend tests under the press.

Bend tests under a press are much easier to make than drop tests and are therefore often made by the firms wishing to develop and follow up a welding process.

This test was used formerly by the French railways when inspecting new rails; it has been replaced by the drop test.

The *Piedmontese Tramways* also carry out this test on complex joints in 18-kgr./m. (36.3 lb. per yd.) rails arc-welded together (table D-7).

TABLE D-7.

Bend tests of 18-kgr. (36.3 lb. per yd.) rails placed on two supports 1.50 m. (4′ 11″) apart.

Piedmontese Tramways Company.

p = kgr. (*lb.*)	Welded rail.		Fished rail.	Reference rail.
	F_1	F_2		
7 000 (*15 430*)	11 (*0.43*)	3 (*0.118*)	11 (*0.43*) (1)	...
8 000 (*17 640*)	...	...	...	24 (*0.94*) (2)
9 000 (*19 840*)	18 (*0.709*)	6 (*0.236*)	...	...
10 000 (*22 050*)	... (3)	...	...	...
11 000 (*24 250*)	...	...	...	...

p = Load, in kgr. (*in lb.*) applied to the rail, half way between the supports.
F^1 = Momentary deflection unter load } in millimetres (*in inches*).
F^2 = Permanent set }
(1) The fishplates did not resume their original shape after being bent.
(2) The rail was bent and did not resume its original shape.
(3) The rail broke outside the weld under a load of 11 000 kgr. (23 150 lb.) approx.

5. Fatigue tests (repeated bend, alternating or not).

This test most closely reproduces service conditions. It ought, therefore, to be used as frequently as possible. Unfortunately the machines required are costly as the force to be exerted amounts to several tens of tons and therefore there are not many in use.

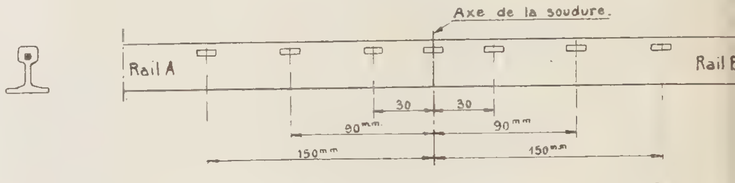
This test consists of placing the welded rail joint on two supports a given distance apart (usually 0.80 m. or 1 m. (2′ 7 1/2″ or 3′ 3 3/8″) and imposing on the middle, i.e. on the joint, a

TA

Tensile and resilience tests on

Laboratory of the French Est Railway.

I. — Thermit-pressure weld with mild steel plate interposed between the heads of the two rails to
welded.

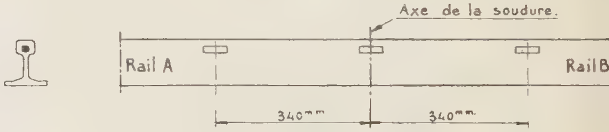


Resilience in kgrm. (ft./lb.) after annealing, the cooling down being done in 3 different ways.								
in the open air. . .	2.9 *(1.9)*	4.6 *(3.1)*	1.1 *(0.7)*	9.3 *(6.2)*	2.7 *(1.8)*	2.1 *(1.5)*	1.3 *(0.87)*
during 15 minutes in an oven, then in the open air	2.0 *(1.3)*	3.9 *(2.6)*	1.1 *(0.7)*	3.6 *(2.4)*	3.4 *(2.3)*	3.8 *(2.6)*	2.5 *(1.7)*
during 1 hour in an oven, then in the open air	1.9 *(1.3)*	4.0 *(2.7)*	1.5 *(1)*	8.1 *(5.4)*	2.7 *(1.8)*	2.5 *(1.7)*	0.9 *(0.6)*

All the test pieces for the resilience tests were cut out of the head of the rail (position *a*).

Note: Axe de la soudure = centre line of weld.

II. — Thermit-fusion weld.



Resilience in kgrm. *(in ft./lb.)*, after annealing, of two welds of the same type.	1.3 *(0.9)* 2.9 *(1.9)*	4.1 *(2.8)* 4.9 *(3.3)*	0.8 *(0.5)* 4.4 *(2.9)*

All the test pieces were cut from the rail head (position *a*).

DEFINITIONS OF THE CHARACTERISTICS DETERMINED BY THE TENSILE AND RESILIENCE TESTS.

Resilience tests.

R = Breaking strength in kgr./mm² of the original section of the test piece.

E.L. = Elastic limit in kgr./mm².

E = Proportional elongation of the part *xy* in fig. D.6 measured after fracture.

Σ = Reduction of area defined by $\frac{S - S'}{S}$.

S = Primitive section of the test piece.

S′ = Section at fracture.

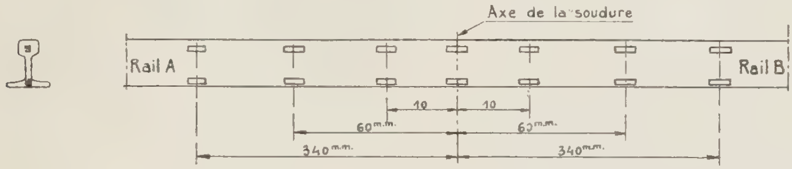
Resilience tests.

The resilience is the number of kgrm. relat
to a cm² of the section at fracture, absorbe
breaking the test piece by a blow from a tup. A
kgr. (66 lb.) Charpy pendulum is the one
rally used.

cut from welded joints.

(The position from which the test pieces were cut is shown in figure D. 6).

- Electric flash weld, followed by annealing for 30 minutes at 950° C.



									Position of the test piece.
ence grm. ./lb.)	in the rail head	0.64 (0.43)	3.39 (2.22)	2.29 (1.52)	2.71 (1.82)	3.61 (2.47)	3.84 (2.43)	3,15 (2.05)	a
	in the foot	1.70 (1.14)	4.45 (2.98)	2.29 (1.52)	3.38 (2.18)	3.15 (2.05)	3.60 (2.42)	3.26 (2.20)	b
ılts nsile ts.	R (kgr./mm²) *Engl. t./sq. in.*	73.5 *(46.7)*			77.8 *(49.4)*			76.5 *(48.6)*	c
	E.L. (kgr./mm²) *Engl. t./sq. in.*	42.6 *(26.7)*			47.3 *(30.1)*			41.8 *(26.5)*	
	E	19 %			8 %			17 %	
	Σ	22 %			40 %			29 %	

Electric flash weld followed by annealing carried out in two different ways :

A) Annealed at 925° C. for 20 minutes.

B) Two successive annealings at 925° C. for 20 minutes.

(The test pieces were cut from the weld.)

		Rail before welding.	Annealing A	Annealing B	Position of the test bar.
silience in kgrm. *(in ft./lb)*	head	0.8 *(0.5)*	4.3 *(2.9)*	2.1 *(1.4)*	a
	foot	1.2 *(0.8)*	1.8 *(1.2)*	1.2 *(0.8)*	b
sile results	Tensile strength	74.8 *(50.2)*	72.0 *(48.4)*	73.2 *(49.18)*	c
	Elastic limit	42.7 *(28.6)*	42.9 *(28.8)*	40.2 *(27)*	
	Elongation	10.6 %	8 %	17 %	
	Σ	33 %	20 %	40 %	

load varying periodically between minimum and maximum values, F_1 and F_2.

When F_1 acts in the direction opposite to F_2, the piece is subjected to alternating bending but when F_1 and F_2 are in the same direction the bending is repeated but not alternating.

In the case of ordinary 46-kgr./m. (92.7 lb. per yd.) rails the required load F_1 would be 40 to 50 tons.

With the testing machines now available, it is not possible to make alternating bend tests with such loads, but only repeated bend tests with the value of F_1, for example, reduced to 1 000 kgr. or 500 kgr. (2 200 lb. or 1 100 lb.).

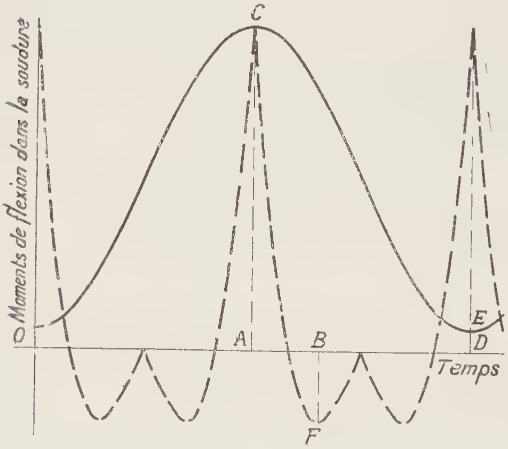


Fig. D. 8. — Diagram showing the variation in the bending of a welded joint.

——— during an alternated bend test (in the laboratory on a machine giving 500 bends per minute.

- - - - - - in the track, when locomotives run over it at 120 km. (75 miles) an hour, the locomotive axles being 2 m. (6' 6 3/4") apart, and the sleepers 0.66 m. (2' 2"). The weld is supposed to be at the middle of the space separating two sleepers.

The maximum bending moment as given by the test machine and by the locomotive are taken as coinciding.

Time { O D = 0.12 sec. (500 bends per minute).
A D = 0.06 sec. (1000 passages per min.) 120 km. (75 miles) an hour.

$\frac{DE}{AC} = 0.02$ to 0.07.

$\frac{BF}{AC} = -0.22$.

The actual strengths of the joints in service cannot be ascertained from these tests, as the trains in running over them set up alternating stresses. As an example, the dotted line of fig. D. 8 shows the variations in the bending moment in terms of the time in a section of a rail half way between two sleepers under a locomotive travelling at 120 km. (75 miles) an hour, with its driving axles 2 m. (6′ 6 3/4″) apart, the sleepers being taken as 0.66 m. (2′ 2″) apart.

The full line shows the variations in the bending moment a repeated bend testing machine can give.

These two curves differ not only by the first corresponding to alternating bending and the second to repeated bending but also by the form of the curve (law of the variation of the load in terms of the time) and the *frequency of bending* (500 bends per minute in the test machine, 1 000 per minute when travelling at 120 km. (75 miles) an hour with axles 2 m. (6′ 6 3/4″) apart).

The two last differences are not important, however, as the results from fatigue tests with rolled steel bars depend on the value of the loads F_1 and F_2 and not on the law of the variation of the load in terms of the time between these two limits, nor on the frequency of the bending, provided the latter is less than about 4 000 per minute. Above this frequency, the test piece heats and this increases its resistance to fatigue appreciably.

Fatigue tests, whether alternating or repeated, on rails or other materials show that when F_2 is high enough the test piece breaks after a certain number of bends which we will denote by the letter N. If the test be started with a lower value of F_2, the piece will break at a higher value of N, and finally if F_2 is below a certain value F, the piece stands an infinite number of bends without breaking. This value F is known as the fatigue limit.

With a view to shortening the test, the

fatigue limit has sometimes been taken as approximately 97 % of a load F_2 under which breakage occurs after some three million bends. This reduction of 3 % was found from tests carried to destruction (fig. D. 5).

The graphical representation of the variation of the load F_2 in terms of the number of bends required to break the test piece is sometimes known as Wöhler's curve (fig. D. 9). It has an asymp-

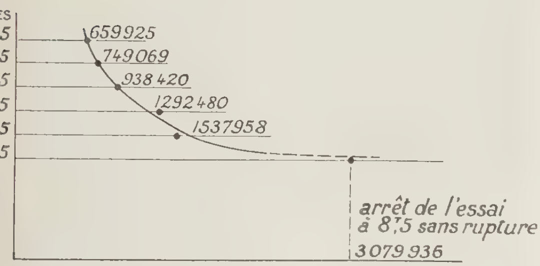


Fig. D. 9. — Woëhler's curve.

This curve is an example of the results of tests made with a « complex » joint similar that of figure B. 14. but oxy-acetylene-welded.
Rails of 46 kgr./m. (92.7 lb. per yd.).
Supports 1 m. (3' 3 3/8") apart.
The test at 8.5 tons was stopped after 3 079 936 bends without any crack having formed.

tote parallel to the axis of the number of bends. The ordinate of this asymptote, measured on the axis of the applied loads, is the fatigue limit.

* * *

II. — Metallographical examinations.

1. Macrographs.

Many macrographs have been taken, by the usual Baumann or Fry methods, on vertical, longitudinal and cross sections through the welds. The following observations were recorded :

a) *Heterogeneity.* — The following different zones are distinguishable :

a 1) *Zone of melted metal.* — The metal shows dendrites lying more or less perpendicularly to the surface of separation of the melted metal (figs D. 10-D. 11). This structure, characteristic of cast metal, does not make the metal particularly brittle when the weld is annealed; annealing, whilst not altering the structure, does in fact increase the resilience of the metal appreciably.

a 2) *Zone in which the metal has not been melted.* — The alignment of the fibres in the rail as rolled are preserved (figs. D. 11 and D. 12).

In thermit-pressure welding with a plate interposed between the heads of the rails, the mild steel of the said plate forms a clearly visible zone in the macrographs (fig. D. 13).

Below this zone, i.e. at the middle of the web, there is a clear space of some 3 cm. (1 3/16″) due to a pocket resulting from the melting of the web, and which has been filled with cast metal. Lower down, the heat from the cast metal has not been sufficient to melt the web near the foot and the filling metal has simply filled up the space between the two rail ends.

On the other hand, the lower part of the rail foot has been in a bath of molten metal and has entirely melted; this explains the clear area of the figure. The parts of the rail melted by the heat of the molten metal are proportional to the surfaces in contact and the thicknesses.

b) *Porosity, blow-holes and piping.* — These defects, met with in steel ingots and castings, are found as a rule outside the joint itself in the excess metal which acts as a header. They occur sometimes however in the web of the rail. Figure D. 14 shows a weld badly made on purpose to show such defects. They are also found near the holes in the moulds through which the preheating flame passes, probably because of the high mould temperature thereat.

c) *Segregation.* — This ingot defect

Fig. D. 10. — Fusion-thermit weld.

Vertical longitudinal section, etched by the Fry method; showing dendrite in the cast metal.

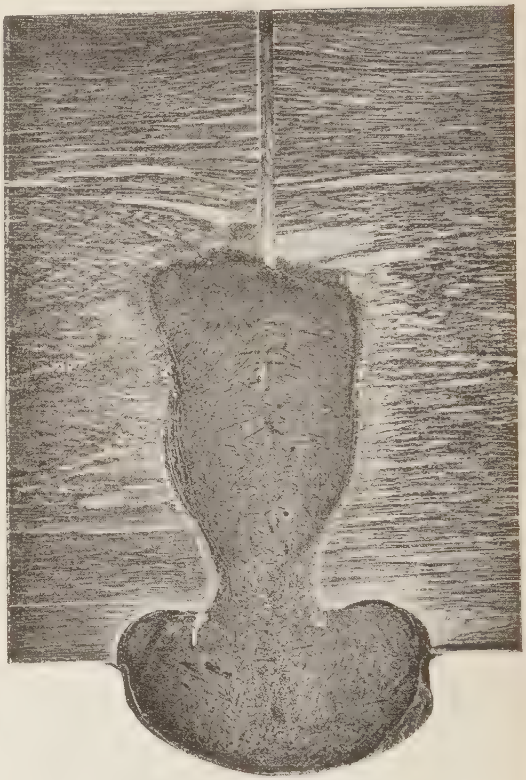


Fig. D. 11. — Thermit-pressure weld (with interposed plate).

Vertical longitudinal section, etched by the Fry method; dendrites, blow holes in the cast metal.

is rarely found in thermit welds because of the purity of the raw materials used.

d) *Forging structure.* — Welds made by the electric process are always completed by applying a forging pressure, and the macrographical structure is that of forged metal. The fibres running through the rail as a result of rolling it turn in at the weld where the rails are upset by the compression applied to them (fig. D. 12). The same structure is found in *thermit-pressure* welding but in the rail heads alone.

The effect of planing the welds to restore the continuous running surfaces is to cut through the fibres in the places machined (fig. D. 15).

e) *Welds parting.* — This defect is rare, whichever process (thermit welding with a mild-steel plate interposed or electric flash) be used. Fig. D. 16 shows such a parting (weld with plate). It leads to the joint breaking (figs. C. 1 and C. 2 of the previous chapter).

2. Micrographs.

a) *General.* — Whichever the welding process used, ferrite and perlite are found as constituents in unannealed welds.

The following structures have been found in unannealed welds :

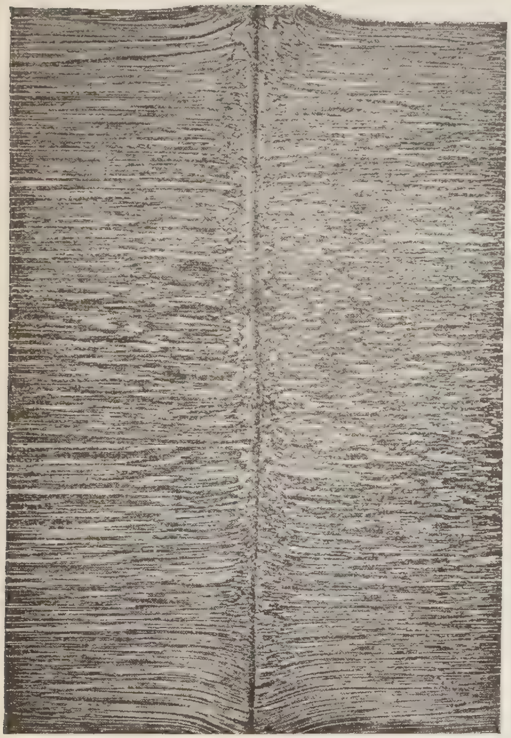


Fig. D. 12. — Electric flash weld.

Vertical longitudinal section after etching by the Fry method (the alignment of the rolling fibres still extant in the zones when the metal has not been melted or forged).

— in the weld itself : very coarse grain with Widmanstätten structure (fig. D. 17).

— a few millimetres from the weld : a coarse-grain structure (fig. D. 18).

— a few centimetres from the weld : a fine-grain cellular structure corresponding to a « self-annealed » zone (fig. D. 19).

Gradually as the distance from the weld increases the structure becomes normal (fig. D. 20).

As is known, course grain structure makes metal brittle.

By annealing after welding, as discussed later, the properties of the metal can be altered, and a finer grain even than in the body of the rail obtained (figs. D. 23 and 24).

Figures D. 22 *a* to D. 22 *g* are micrographs supplied by the *Paris-Lyon-Mediterranée* Railways from flash-butt welded rails.

Fig. D. 13. — Thermit-pressure weld with interposed plate.

Vertical longitudinal section. Etched by the double copper-ammonium chloride process, showing :

Light area at the top: the metal of the interposed plate.

Light central area: the web metal melted accidentally.

At the bottom: the added weld metal.

Between te added metal and the melted part of the web: the white band represents the original space between the two rails, which has been filled with the added metal.

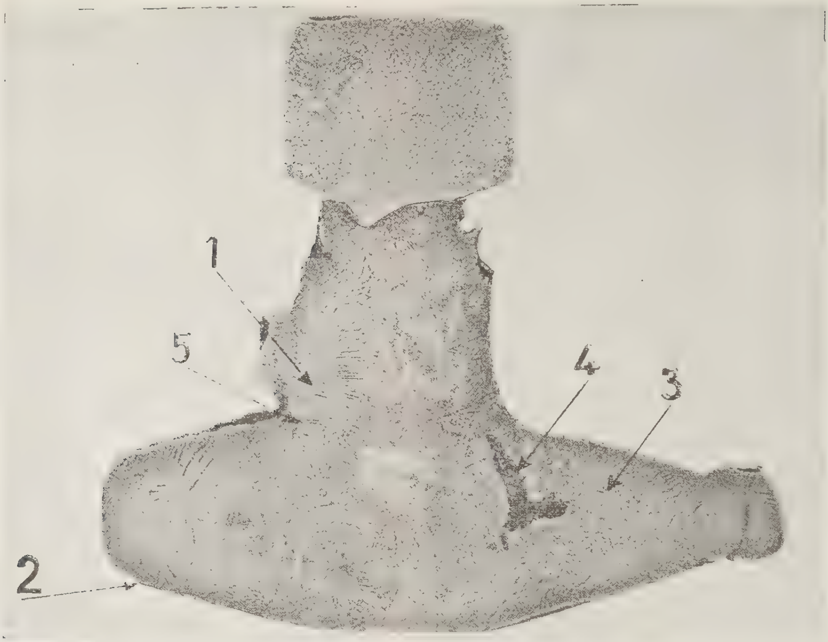


Fig. D. 14. — Thermit-pressure weld.

Vertical longitudinal section etched by the « Fry » method.
An intentionally badly made weld, to show the defects in a defective cast:

1.
2. } Dendrites. — Much marked at (1) near the opening through which the preheating flame is directed.
3.
4. Piping.
5. Blow-hole.

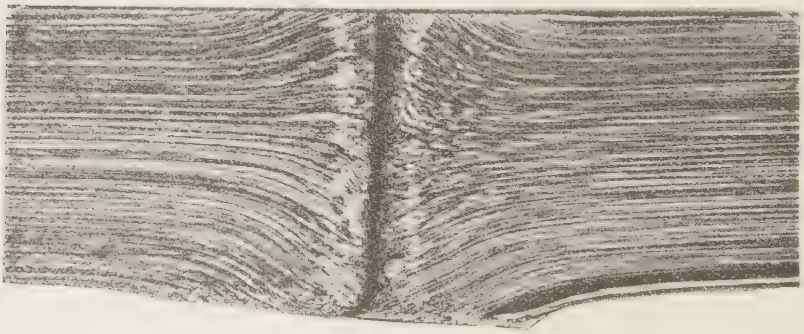


Fig. D. 15. — Electric flash weld.

Horizontal section through one wing of the foot of a rail (magnified 2 1/2 times), showing the incurvation of the fibres near the weld and the way they are cut through by planing.

Fig. D. 16. — Thermit-pressure weld with interposed plate, broken in service owing to bad workmanship (the plate has parted from the head).

The visible lines on the section of the rail head are tool marks left when planing the section before welding. The fact of these marks not being destroyed by the weld proves that the plate was merely stuck to the rails and not welded.

The three micrographs *a*, *b* and *c*, are from an unannealed weld. The micrograph *c*, taken before annealing, at a distance of 20 mm. (25/32″) from the weld shows that there was some reduction in the size of the grain by self-annealing. The three micrographs are from an annealed weld. These show how the structure of the metal has been improved by annealing.

b) *Structure of unannealed thermit welds*. — In the pressure process with a plate interposed between the rail heads, the size of grain in the plate increases appreciably during the welding (fig. D. 23, plate before welding; D. 24, plate after welding). After the weld has been annealed as described below the grain in the plate becomes even finer than in its natural state (fig. D. 24*bis*).

Close to the plate the Widmanstätten

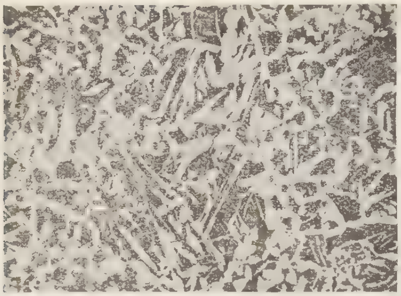


Fig. D. 17. — Widmanstätten structure in an unannealed weld (65 diam.).

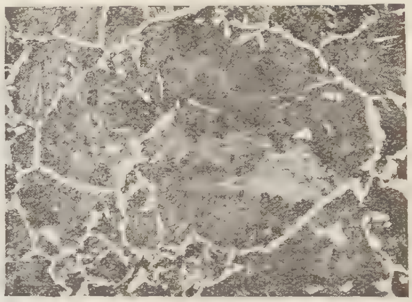


Fig. D. 18. — Unannealed electric weld. Increased grain in the zone adjacent to the weld (65 diam.).

(Very coarse grains of perlite embedded in the ferrite.

Fig. D. 19. — Unannealed electric weld. Self-annealed zone 70 mm. (2' 3/4'') from the weld in the rail head (65 diam.).

The finer grain will be observed (white marks, ferrite; black marks, perlite).

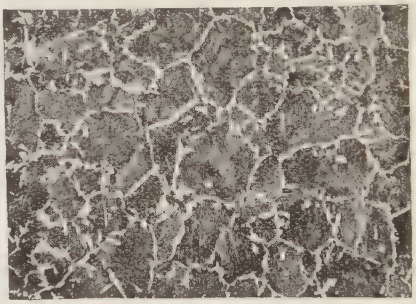


Fig. D. 20. — Unannealed electric weld (65 diam.).

Structure of the natural metal (coarse grains of perlite embedded in the ferrite).

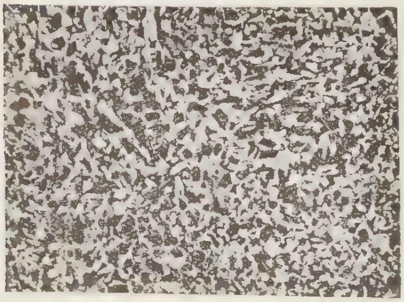


Fig. D. 21. — Annealed thermit-pressure weld with interposed plate.

Rail head near the weld (65 diam.). The finer grain through annealing will be observed.

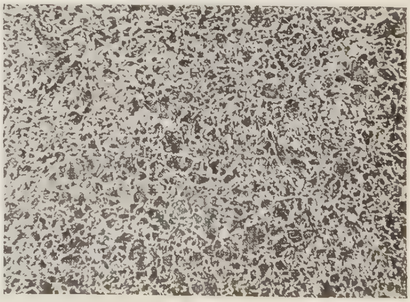
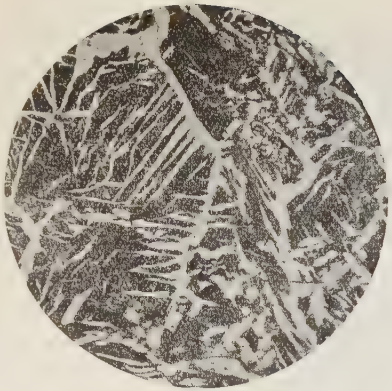


Fig. D. 22. — Annealed electric flash weld.

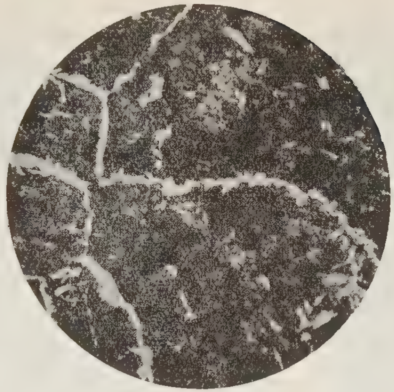
Micrograph in the weld of the rail head (65 magnifications). The finer grain due to annealing will be observed.

Unannealed weld.

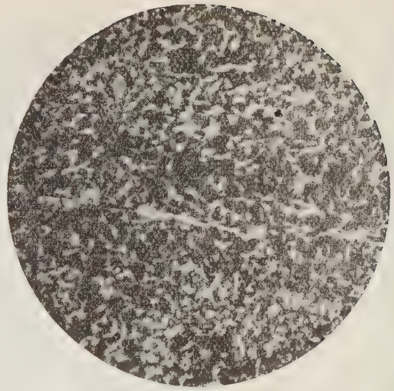
a



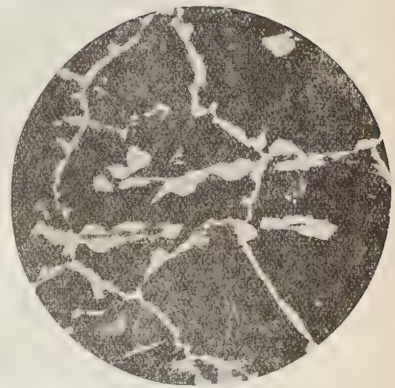
b



c



g

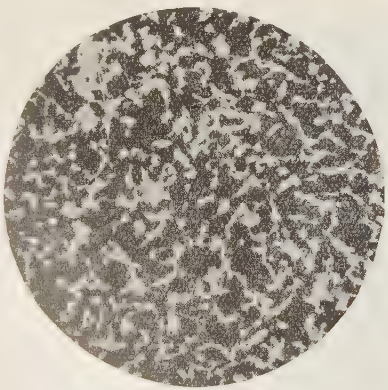


Original condition of rail.

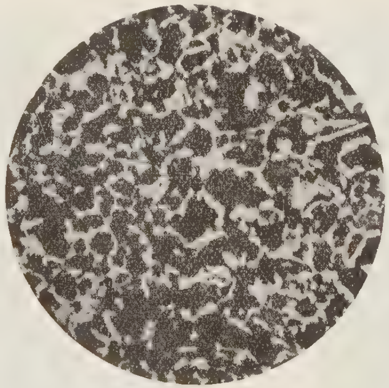
Acicular structure in the weld itself.	*Overheated zone. Course grain, 3 mm. (1/8") from the weld.*	*Self-annealed zone: finer grain, 20 mm. (25/32") from the weld.*

After annealing the grain size is more or less the same everywhere.

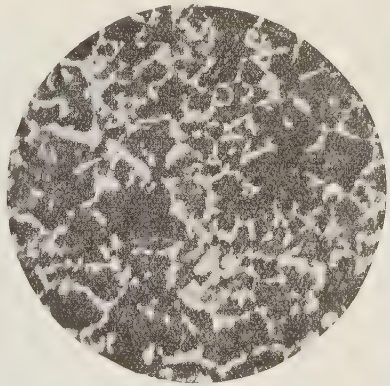
d



e



f



Annealed weld.

Fig. D. 22*a* to D. 22*g*. — Micrographs of electric flash welds (125 diam.) *P. L. M.* Railway (*France*)

Legend:

a, b, c. — Micrographs of an unannealed weld.
d, e, f. — Micrographs of a weld annealed at 800° C. for 40 minutes, then cooled in the open.
g. — Original condition of rail.

Fig. D. 23. — Mild steel plate for thermit-pressure weld.

Longitudinal micrograph before welding (fine grains of ferrite) (65 diam.).

Fig. D. 24. — Mild steel plate for thermit-pressure weld.

Micrograph taken after welding without annealing. The increased grain size will be noticed (65 diam.).

Fig. D. 24 *bis.* — Mild steel plate for thermit-pressure weld.

Micrograph taken after annealing the weld. The improvement in the structure through annealing will be noticed. The grain size is smaller than in the original metal (65 diam.).

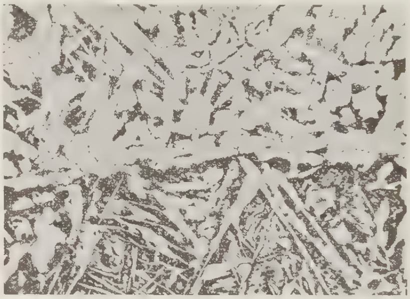


Fig. D. 25. — Thermit-pressure weld unannealed.

Micrograph of the junction between the plate and the rail head. The highly developed Widmanstätten structure in the lower part corresponding to the rail head will be noticed (65 diam.).

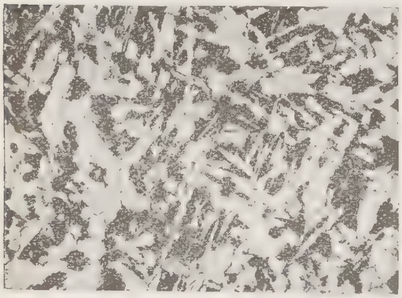


Fig. D. 26. — Thermit-pressure weld unannealed.

Micrograph of the web (the web being partially melted the Widmanstätten structure will be seen) (65 diam.).

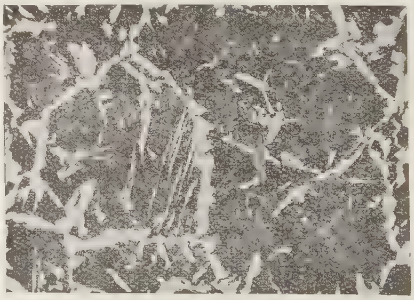


Fig. D. 27. — Thermit-pressure weld unannealed.

Micrograph taken in the rail head near the weld [coarse grains (black), perlite — white needles, ferrite] (65 diam.).

Fig. D. 28. — Unannealed electric weld.

Micrograph in the rail head. Widmanstätten structure (65 diam.).

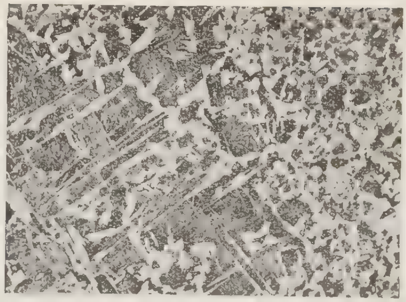


Fig. D. 29. — Unannealed electric weld.

Micrograph in the web. The Widmanstätten structure in the overheated zone near the weld will be noticed (left side of the figure). Large islets of Widmanstätten structure embedded in unchanged metal (65 diam.).

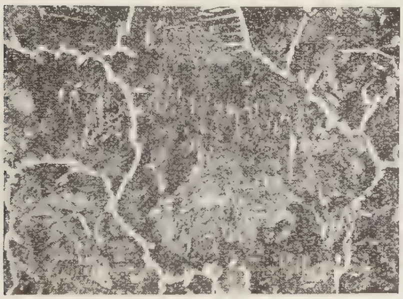


Fig. D. 30. — Unannealed electric flash weld.

Micrograph of an area near the weld in the foot. Polygonal structure with coarse grains of perlite (65 diam.).

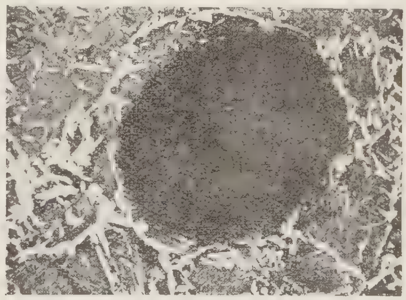


Fig. D. 31. — Thermit-pressure weld.

Blow-hole in the foot (65 diam.)

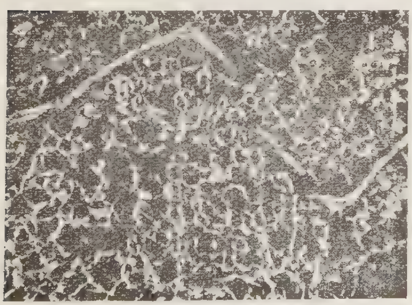


Fig. D. 32. — Electric flash weld.

Micrograph taken from the foot. — Inclusions in the ferrite partially outlining the contours of the gamma grains of the first crystallistion (65 diam.).

Fig. D. 33. — Electric flash welding.

Another micrograph from the foot. Inclusions in the ferrite partially outlining the contours of the grain (65 diam.).

structure is very much developed (fig. D. 25) as it is in the area of melted metal (fig. D. 26). Close to the weld, the structure is acicular (in the form of needles) (fig. D. 27).

c) *Structure of unannealed electric welds.* — In the weld itself, we find the Widmanstätten structure and in the adjacent zones a reticular structure of very large systems (figs. D. 28, D. 29 and D. 30).

d) *Inclusions.* — Inclusions of oxides are sometimes found in the welds, and occasionally in some thermit welds (fig. D. 31) small blow holes.

These inclusions are located round the grain of the first crystallization during cooling (gamma grains in micrographical work); after annealing they are not divided by the alteration of the grain and are seen as filaments imprisoned in the ferrite (fig. D. 32 and D. 33).

There should be no sand inclusions from the moulds if the welding is properly carried out.

* * *

III. — Magnetic examination of the surface.

This examination is made to show up any cracks which may exist in the weld. The surface to be examined is carefully polished and then magnetised for example by passing over it a horse shoe permanent magnet (contact magnetisation). A sheet of paper laid between the magnet and the surface prevents it being scratched.

The magnet is moved over the surface at about 45° to the direction of rolling so that the magnetic field created in it is cut by fissures parallel to the line of rolling as well as by those at right angles thereto. The surface is then covered with spirit containing extremely finely divided iron obtained by reducing iron oxide by hydrogen.

The magnetic field is irregular over any cracks, the iron accumulates, and so reveals the cracks.

* * *

IV. — X-ray examinations.

This method is very valuable, as the parts can be examined without damaging them.

It is in general use for checking welds, especially in boiler work and structural work. The defects revealed are : blow-holes, inclusions, incomplete fusion, adhesions, cracks, etc...

As to the extent of the defects revealed, a defect in homogenity the width of which is 1 % of the total thickness is revealed when the latest X-ray tubes with their smaller field, with better reinforcing screens, and films are used.

X-ray testing can now be applied to rail welds. With the 200 000-volt tubes now manufactured a depth of 80 mm. (3 1/8″) of steel can be explored, and with 400 000-volt tubes a depth of 130 mm. (5 1/8″).

X-ray examination, however, is rarely used in examining rail welds : the reason is the relatively high cost, some 40 French francs per weld tested. Furthermore, the sensitivity of 1 % mentioned above is not sufficient. Cracks of much less size can be dangerous and ought to be revealed. With certain particular operating precautions, this sensitivity can nevertheless be increased. An example is (fig. D. 34) the reproduction af an X-ray film from a properly carried out thermit-fusion weld on which the two heterogeneous zones are visible. The X-ray examination has been made of the whole weld without damaging it.

A subsequent section through one of these zones, as shown in figure D. 35, shows very small blow-holes which are visible in the macrograph, figure D. 36.

To sum up, of the three methods by which the largest amount of useful in-

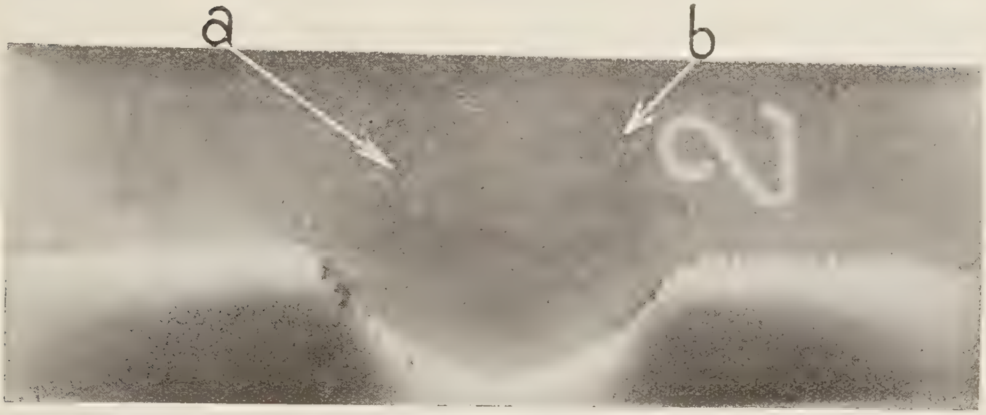


Fig. D. 34. — Reproduction of an X-ray film of a thermit-fusion weld.

Note. — *a* and *b*. Heterogeneous areas.

formation can be obtained (drop test, fatigue (alternated bending) test and X-ray examination) the drop test is by far the most widely resorted to, because all railway companies are in possession of the necessary equipment, and because it is the cheapest and quickest method. However welding work is done under conditions so different from current practice that the value of a weld should not be judged from this kind of test alone.

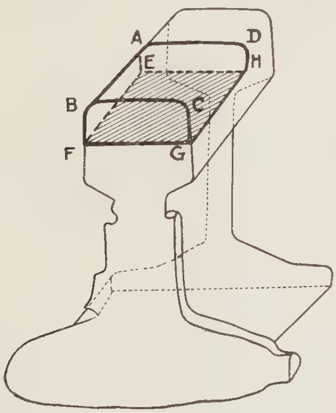


Fig. D. 35. — Diagram of part of the weld of which figure D. 34 is the X-ray photograph.

To get to the heterogeneous area *a* of fig. 34, the part A B C D E F G H was cut from the rail head, the plane E F G H selected passing through the zone *a*.
The surface E F G H, on being etched, revealed small blow-holes.

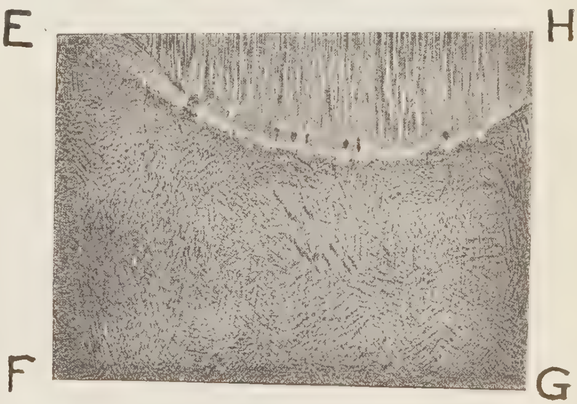


Fig. D. 36. — Macrograph of the surface E F G H of figure D. 35.

A series of very small blow-holes will be noticed at the edge of the metal melted during welding.

D-2. — Annealing the welds.

As has just been pointed out, unannealed welds are sometimes brittle owing to the presence of zones with a Widmanstätten structure and coarse grains

revealed by the micrographical examinations.

The object of annealing is to remove these defects, and consists in heating the weld above the critical point of the Ac 3 steel, i.e. about 850° C., followed by a more or less quick cooling according to the effect desired.

The three characteristic factors in annealing are :

1. the temperature to be attained;
2. the duration of the heating, with its two periods of raising the temperature and holding it constant;
3. the rate of cooling.

These three factors are arrived at by experience.

1. Temperature to be attained.

The weld has to be heated above the critical point known as the Ac 3 point in heat analysis, but not very much, so as not to increase the grain size. A temperature of about 850° C. is usual with 0.4 % carbon rails.

In practice the weld can be heated in place by a petrol blow lamp, the muffle of refractory earth being built up round the weld so as to equalise the heating as much as possible. Various ways of doing this are in use.

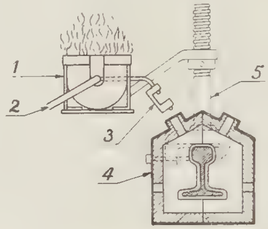


Fig. D. 37. — First example of an annealing furnace.

Legend :

1. Wood charcoal heater.
2. Petrol supply.
3. Burner.
4. Muffle in refractory material.
5. Screw supporting the muffle.

Fig. D. 37 shows one of them (petrol gasified by heating it over a charcoal furnace).

Fig. D. 38 shows another patented process (atomization of the petrol under a low pressure (0.14 hpz. = 2 lb. per sq. in.) and controlled air supply from a fan).

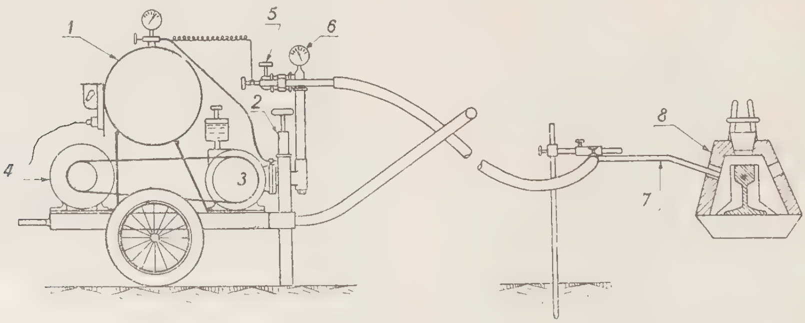


Fig. D. 38. — Second example of an annealing furnace.

Legend :

1. Petrol tank.
2. Air pump maintaining a pressure of 2.5 kgr. (35.5 lb. per sq. in.) in the tank.
3. Fan.
4. Electric motor driving fan.
5. Petrol jet.
6. Pressure gauge of gas mixture.
7. Burner.
8. Muffle in refractory material.

In the shops this heating can be done in a producer-gas or oil-fired furnace which can take a number of welds at a time.

2. Duration of heating.

This period is ascertained by trial and error according to the equipment available. The maximum annealing temperature must be maintained in the metal as short a time as possible, but the whole mass of metal must be raised to this temperature.

If the temperature be held too long above the critical point, the grain may become coarser.

The rise in the temperature is controlled by pyrometers. These instruments, however, whether optical, contact or thermo-electric, only give the surface temperature of the rail.

If the temperature is raised too quickly it is possible to be deceived by a reading, owing to the middle of the rail not yet having reached the annealing temperature.

Slow heating allowing the heat to permeate uniformly all parts of the rail section, without the parts near the surface being too hot, appears better than quick heating.

3. Rate of cooling.

The welded joint should be cooled as quickly as possible so as to prevent bands of ferrite being formed in the direction of rolling. When such bands are formed the rails are more likely to be crushed down by the running surface flaking.

The rate of cooling must not be too high, however, to prevent internal stresses being set up by unequal cooling throughout the rail section.

In practice the rail joints can be allowed to cool down inside the refractory envelope for a certain time after the welding is completed, or this envelope can be removed immediately after heating up the joint, or the joint can be cooled artificially after stripping the mould by a patented process, by spraying water or by a jet of compressed air.

The curves of figs. D. 39 and D. 40

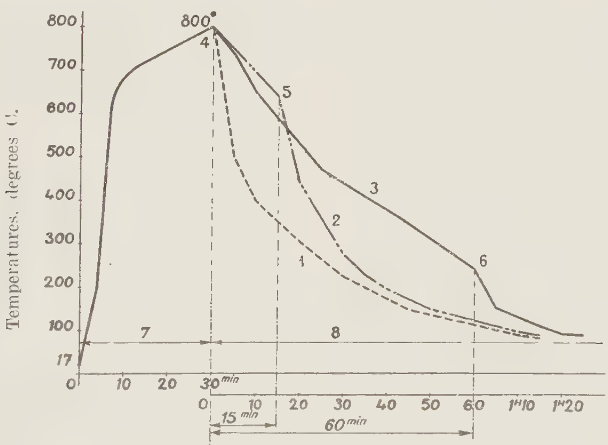


Fig. D. 39. — Curves of the temperature changes recorded when annealing electric flash welds.

The cooling down curves 1, 2, 3 correspond to the three following methods of operation:

Curve 1. — Removing the muffle as soon as the heating is stopped.
Curve 2. — Removing the muffle 15 minutes after the heating is stopped.
Curve 3. — Removing the muffle 1 hour after the heating is stopped.

4. Heating stopped.
5. Muffle removed (curve 2).
6. Muffle removed (curve 3).
7. Heating period.
8. Cooling period.

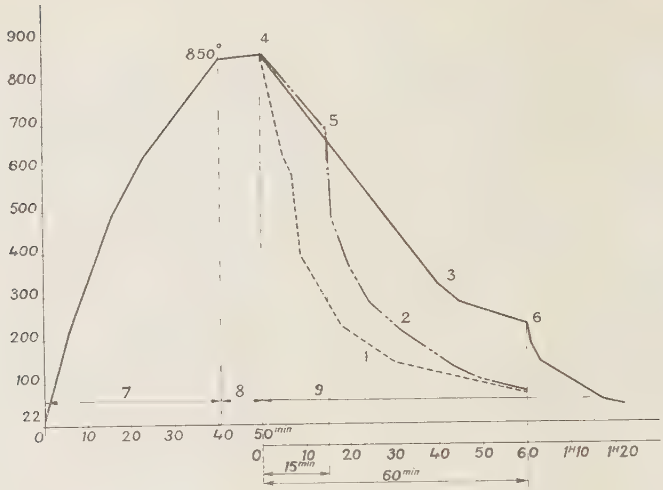


Fig. D. 40. — Curves of the temperature changes recorded when annealing thermit-pressure welds.

The cooling down curves 1, 2 and 3 correspond to the three following methods of operation:

Curve 1. — Removing the muffle as soon as the heating is stopped.
Curve 2. — Removing the muffle 15 minutes after the heating is stopped.
Curve 3. — Removing the muffle 1 hour after the heating is stopped.

4. Heating stopped.
5. Muffle removed (curve 2).
6. Muffle removed (curve 3).
7. Heating period (normal rate).
8. Moderate heating period.
9. Cooling period.

are examples of the variations of the rail surface temperature in terms of time recorded by a thermo-electric pyrometer during annealing.

* * *

D-3. — Welding heat-treated rails.

Annealing the weld is one of many forms of heat treatment. The expression is often used in connection with the manufacture of rails to describe the surface hardening of the running surface, followed automatically by a tempering by the heat imprisoned in the foot of the rail. This heat treatment, or more correctly hardening is applied constantly on a wide scale to rails supplied to the French Railways. Some railways for many years have ordered all their rails heat-treated in this way, i.e. by immersing the rail head in water (French *Est*). This hardening is completed in some cases by passing the rails through furnaces to retard the cooling. As mentioned above, the heat in the foot and web which have not been quenched anneal the rail head by conductivity to some extent.

This heat treatment or hardening gives the following advantages :

1. Crushing of the rail head is reduced, flaking being to all intents and purposes unknown (the process increases the hardness of the running surface, by the sorbitic formation it induces).

2. The rails are much less brittle, possibly due to using a milder steel (60 kgr./mm² = 38.0 tons per sq. inch, instead of 70 kgr./mm² = 44.4 tons).

3. The hair cracks set up on the running surface of the rails by wheel slip develop less quickly in treated than in untreated rails, due probably to the sorbitic structure.

4. As the hardening only gives good results when the steel is well made an

indirect result of the treatment has been to improve the rail metal itself.

These advantages are recalled solely because of their value to the railways. Some of them (French *Est* and *P. O.-Midi*) use nothing but treated rails. As in future all new rails welded will be treated rails, the welding processes must be adapted to such rails by applying a suitable re-treatment after welding.

The French railways are testing treated rails, welded by the thermit-fusion process. As the heat treatment is destroyed in welding, the weld has to be re-heat-treated, which is done by a patented process consisting essentially in reheating the rail followed by directing a jet of water on the surface of the head. The tempering is due to the heat accumulated in the web and foot.

Drop tests with a 300-kgr. (660 lb.) tup, made on the French *Nord* and *Est* Railways are encouraging. The first length of rail broke under a drop of 11 m. (36′ 1″), the second after 13 m. (42′ 8″), figures never previously attained in such tests. The third length was tested only with a drop of 5.22 m. (17′ 1 1/2″) and stood 18 blows with the 300-kgr. (660 lb.) tup before breaking.

* * *

CHAPTER E.

Application of welding to rails.

I. — Worn rails with the ends cut off.

Most railways have welded worn rails with the ends cut off to remove the most worn parts and the fish-plate holes. The length cut off each end varies between 0.35 m. and 0.75 m. (13 3/4″ to 29 1/2″) on different railways. Rails of the usual lengths and of uniform quality are thereby obtained from the sound parts of rails taken out of service.

These rails can be used on the through roads on secondary lines.

If the rail ends after cutting off are bent, they are straightened under a press before welding; any flaking on the running surface is planed off.

The *Alsace-Lorraine* Railways, by cutting off 0.75 m. (29 1/2″) from each end of 12 and 15-m. (39′ 4 1/2″ and 49′ 2 1/2″) rails and welding two of them together obtain 21 and 27-m. (68′ 10 3/4″ and 88′ 7″) rails. The amount, 0.75 m. (29 1/2″) cut off each end may appear more than is needed to remove the most worn parts of the rail, but was chosen so that the welded rails should be multiples of 3 metres to facilitate renewal.

The *P. O.-Midi* Railways cut down the old rails to 10 m. so as to get rails 20-m. long (42 kgr./m. = 84.7 lb. per yd. bull-headed rails).

The French *Est* gets 22-m. (72′ 2 1/8″) rails from two 12-m. (39′ 4 1/2″) rails from which 0.50 m. (19 11/16″) is cut off each end.

Large numbers of rails a few centimetres shorter than the ordinary length are also obtained by welding and are used for example on the insides of curves (example : 17.96-m. = 58′ 11″ lengths on track laid with 18-m. = 59′ 5/8″ rails). Rails in different states of wear are also welded together for maintenance purposes.

Finally, defective rails taken out of the track for cracks, splits etc., have had the defective parts cut out and the sound parts have been welded into 18-m. and 20-m. lengths.

Most of the welded rails in service on the *French Nord* running roads, excluding tunnels and bridges, have been made from recovered 46-kgr./m. (92.7 lb. per yd.) and 45-kgr./m. (90.7 lb. per yd.) rails 12 m. (39′ 4 1/2″) long, 0.35 m. (13 3/4″) being cut off each end, and the rails being welded together two by two into 22.6-m. (74′ 1 3/4″) rails.

* * *

II. — Composite rails obtained by welding.

We call composite rails those formed of two lengths of rail of different sections welded together.

They are used to do away with cranked fish-plates which are always a weak point in the track and are expensive to maintain.

The composite rails are used :

1. to connect points and crossings with the running track when the rail sections are different;

2. to connect with grooved rails such as the 70-kgr. (141.1 lb. per yd.) rails used at some level crossings;

3. to connect with the special rails in docks, private sidings, etc.;

4. to connect two rails with different degrees of wear. Examples : new 46-kgr./m. and 44-kgr./m. rails worn from 0 to 4 mm. (5/32″).

The length of composite rails varies very much, as usually they are inserted between points and crossings, and the running roads, so that the length is determined by the position of the points and crossings; as a rule they are not longer than the standard rails.

The welding process used depends on the difference between the sections of the two rails to be welded.

When there is little difference between the section as for example between 45-kgr./m. and 46 kgr./m. rails, or new 46-kgr./m. and 46 kgr./m. rails worn 2 mm. (5/64″), thermit-pressure or electric butt-flash welding can be used.

If there is a greater difference, as for example if 46-kgr./m. rails are to be joined up to 41-kgr./m. with different widths of head, the above processes are not suitable, as usually it is impracticable to get both the running surfaces and the centre lines to coincide and any forging pressure would set up a torsion in the composite rail. In this case thermit-fusion welding has to be used. Rails differing in weight by not more than 10 to 12 kgr./m. (20 to 24 lb. per yd.) can be welded in this way (*Jugoslav State* and *Czechoslovak State* Railways).

If the two sections are very different, as for example when welding a grooved rail to a flat-bottomed or a bull-headed rail, the thermit-fusion process has been used successfully (*French State*) although the preferred method is arc welding, as shown in fig. E. 1 (*French State*).

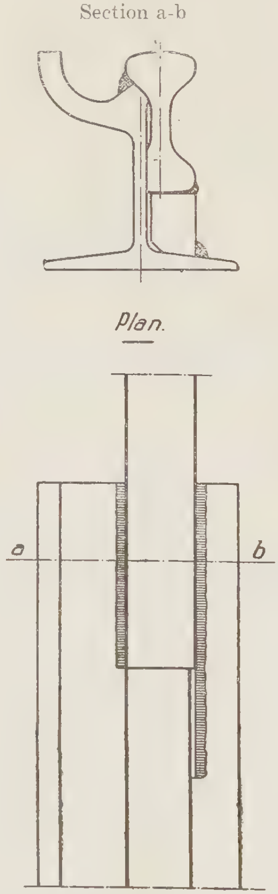


Fig. E. 1. — Electric arc weld of a grooved rail with a double-headed rail (*French State*).

Another method of connecting a grooved rail and an ordinary rail is to use a special manganese or nickel-chrome cast steel rail with the ends of the same sections as those to which it is to be joined and then to weld the two joints.

Still another way is to forge one of the ends of say a 50-kgr./m. rail to another section, say 45 kgr./m., and then weld them together.

The French Nord has succeeded in electrically welding together by the butt-flash process rails of considerable difference in section, such as a 55-kgr./m. (110.9 lb. per yd.) rail to a 46-kgr./m. (90.7 lb. per yd.) rail after machining the ends so as to make the sections come into contact alike.

Figure E. 2 is an example of this method.

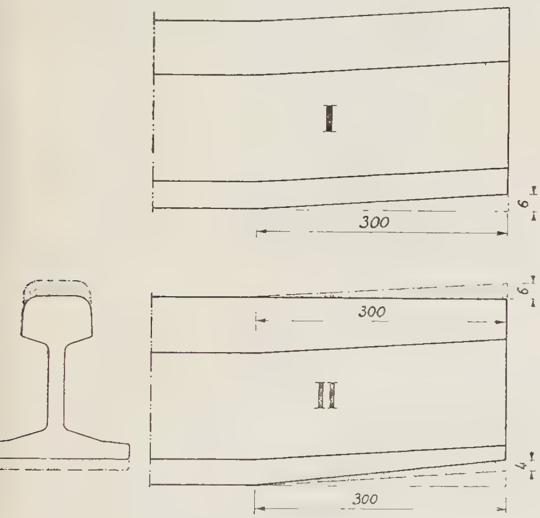


Fig. E. 2. — Electric flash weld of two rails of different section (55 and 46 kgr./m. = 110.9 and 92.7 lb. per yd.).

Legend:

I. Vertical set in the 55 kgr./m. rail so that, its web coincides with that of the 46-kgr. rail.

II. Planing the foot and head of the end of the 55-kgr. to obtain the same section as that of the 46-kgr. rail.

III. — Extra-long rails.

1. In tunnels

Most railways have welded rails for the running roads in tunnels, run over by heavy trains (maximum axle load 21 tons) at high speeds (up to 120 km. = 75 miles an hour). The continuous lengths obtained by welding on the various railways are as great as 48 m., 54 m., 72 m., 96 m. and 108 m. (157′ 5 3/4″, 177′ 2″, 236′ 2 3/4″, 314′ 11 1/2″ and 354′ 4″) (*French State*), and even 288 m. (844′ 10 1/2″) on the *French Nord*. Certain railways have even gone so far as to weld the rails in tunnels into a single length of 981 m. (3 228′ 6″) (*Rumanian* State) and 1 200 m. (3 937′) (*Jugoslav* State).

So that these long rails shall be affected by temperature changes as little as possible, their ends are kept some distance inside the tunnel. From these ends rails of decreasing lengths are laid (fig. E. 3).

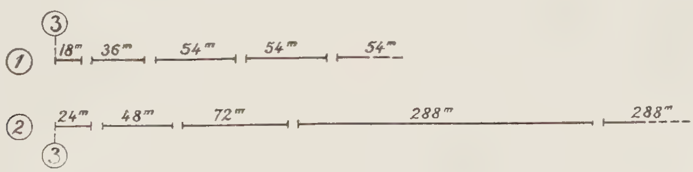


Fig. E. 3. — Examples of the arrangement of extra long rails in tunnels.

1 *Alsace-Lorraine.*

2 *French Nord.*

3 Portal of tunnel.

The difficulty of handling the rails and the time required to replace them if broken are given as reasons for not using very long welded rails in tunnels, but these difficulties can be overcome. The long rails can now be carried without hindrance even over points and crossings and through curves.

As an example the *French Nord* proceeds as follows when laying 288-m. (844′ 10 1/2″) rails in tunnels.

A temporary welding yard is set up near the tunnel. The rails are thermit-pressure welded into single-piece lengths of 144 m. (236′ 2 3/4″).

These rails are coach-screwed to their sleepers in the yard itself and the complete 144-m. length of track is placed on small trolleys 12 metres apart and conveyed to the site where they are to be laid, along the track to be renewed. There is no difficulty in working over curves of 500 m. (25 chains) radius.

A 144-m. length of old track is lifted and the new length is put into place with the help of small gantries on runways on each side of the track. When two 144-m. lengths are in position they are welded together by the thermit-pressure process into 288-m. rails. All the coach screws are slackened off so as not to interfere with the forging pressure.

100-m. (328′) lengths of welded rails not on sleepers have also been conveyed without difficulty by trolleys 12 m. (39′ 4 1/2″) apart over sections of the line with 150-m. (7 1/2 chains) curves.

The rails are off-loaded on the site by means of small portable gantries resting on the ballast.

30-m. (98′ 5 1/8″) rails have been conveyed some ten kilometres (6.2 miles) by using a motor trolley to haul the special trolleys in three sections known as « triplorys » on which the rails are carried.

Handling and transport, therefore, do not prevent the use of extra-long rails.

As regards breakage this is becoming much less frequent, and when it does occur a temporary repair can always be made without interfering with the train service.

Timis tunnel (Rumania).

The diagram, figure E. 4, shows an

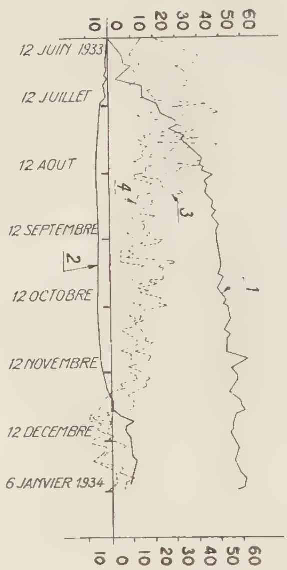


Fig. E. 4. — Elongation of a 975-m. (3 208′ 10″) welded rail recorded during the first months' service. *Rumanian State* — Timis tunnel.

Legend:

——— Movement of each rail end.
1. End at the tunnel outlet.
2. End at the tunnel entrance.
- - - - - Air temperature at the tunnel entrance.
3. Maximum temperatures.
4. Minimum temperatures.

interesting feature observed by the *Rumanian State* Railways on 975 m. and 980.5 m. (3 208′ 10″ and 3 236′ 10″) long rails laid in 1933 in the single-track Timis tunnel.

From the date the two rails were laid they gradually increased in length for the first three months, the increase being as much as 60 mm. (2 3/8″).

No appreciable alteration was noted during the next two months. In the

cold weather period, November to January 1934, the rails only contracted about 15 mm. (19/32″) so that they have increased permanently 45 mm. (1 25/32″) or $\frac{0.045 \text{ m.}}{975 \text{ m.}} = 0.046$ mm./m. = 46 microns per metre.

This permanent elongation is thought to be due in all probability to the liberation of the internal stresses.

2. **On main lines outside tunnels.**

Railways using welded rails in running roads outside tunnels as a rule weld them into lengths not very much longer than their ordinary rails.

For example, the following lengths are found :

27 m. (88′ 7″) on the *Alsace-Lorraine;*
22 m. (72′ 2 1/8″) on the *French Est;*
22.60 m. (74′ 1 3/4″) on the *French Nord;*
20 m. (65′ 7 3/8″) on the *P. O.-Midi;*
25 m. (82′ 1/4″) on the *Czechoslovak State;*
26 m. (85′ 3 5/8″) on the *Jugoslav State.*

There are a few zones of lines with longer rails such as :

36 m. (118′ 1 1/4″) on the *Egyptian State* (1 km. = 0.62 mile of track laid);

36 m. (118′ 1 1/4″) on the *French State* (two consecutive lengths, i.e. 72 m. of track on the Paris-Rouen line);

36 m. (118′ 1 1/4″) on the *Rumanian State* (10 rails of 36-m. length laid near the Timis tunnel);

30 m. (95′ 1 5/8″) on the *Czechoslovak State* (5 km. = 3.1 miles of track on the Usti-Chomutov line);

30 m. (98′ 1 5/8″) on the *Jugoslav State* (718 m. = 0.45 mile of track on the Zagreb-Susak line).

Longer lengths are only recorded in the following particular cases :

a) On metal bridges, the *French Nord*, the *Indo-China & Yunnan*, and the *Czechoslovak State* Railways weld the two pairs of rails into bars the full length of the bridge.

This arrangement is possible because the relative expansion between the rail and the bridge floor is much less than the absolute expansion of the rail.

At the ends of bridges of over a certain length (50 m. = 164′ 1/2″ in France), expansion devices are used to connect the track on the bridge to the access roads (see chapter G, figs. G. 3 and G. 4).

On very long bridges with a number of sections free to move relatively to one another an expansion device is fitted between each of these sections. At the fixed points on each section, the rails are rigidly fastened to the bridge.

b) In stations, on lines *between two platforms.*

Such rails are protected to some extent from direct sunlight. The track is also held transversely by the platform walls so that there is less danger of the track getting out of line transversely through the compression due to a rise in temperature. The *Czechoslovak State* Railways report that 40-m. (131′ 2 3/4″) welded rails are used under these conditions, and they intend to lay others 45 m. (147′ 7 3/4″) long.

c) Finally the *Egyptian State* Railways in 1933 laid between Cairo and Helwan, as a trial, a pair of rails 1 000 m. (3 280′) long.

3. **In sidings.**

The name sidings includes track in shunting yards, service sidings in stations, empty stock lines, etc.

The Companies consider that, broadly speaking, the rails need not be free to expand to the full extent in such sidings as they are sunk in the roadbed, the ballast is consolidaded and the track thus held securely in place. The six-foot is usually filled up.

Transverse deformations through the

rails being in compression are less to be feared than in the running lines. The only thing to be feared is the road lifting and this is not serious in sidings.

The transverse forces imposed by the locomotives are much smaller on such track as the speed is lower. Then too, even if the track did get out of line transversely, the risk of derailment is also less.

As a result many railways have welded rails into much longer lengths than on their main lines. For example rails of the following lengths are found :

54 and 60 m. (177′ 2″ and 196′ 10 1/4″) on the *Alsace-Lorraine* with the same gaps as for 18 m. (59′ 5/8″) rails on the running roads;

36 m. (118′ 1 1/4″) on the *French Est;*

30 to 77 m. (98′ 1 5/8″ to 252′ 7 1/2″) on the *French State*.

This latter railway has laid rails 282 m. (925′ 2 1/2″) long in one of the sheds at Cherbourg Maritime Station where the temperature variation is only about 20° C. (36° F.). When rails are laid in paved roads, they can be welded from end to end as on tramways.

The *French State* Railways have welded lengths of 2 000 m. (6 560′) in one piece, the *French Nord* 100 m. (328′); and the *Czechoslovak State* Railways 90 m. (295′ 3 3/8″) with expansion joints; two rails 300 m. (984′ 3″) long have also been laid.

* * *

CHAPTER F.

Expansion in constrained rails.

1. Extreme temperatures.

The extreme rail temperatures recorded with metal thermometers laid on top of the rails in the various European countries which have supplied information on this subject are approximately :

Maximum temperature : 60° C. (140° F.).
Minimum temperature : — 20° to — 25° C. (— 4 to — 13° F.), and even — 33° C. (— 27.4 F.) in Jugoslavia.

There is therefore a temperature range of at least 80° C. (144° F.).

2. Rules applied when laying rails of ordinary lengths.

The rules for laying ordinary length rails provide for the free expansion and contraction of the rails between these limits, i.e. over a range of more than 80° C. (144° F.). Thus the rail gaps in France (by Ministerial decree) have to be such that the rails can only come into contact at 60° C. (140° F.), the coefficient of expansion being taken as equal to 10.5×10^{-6}.

The gap is calculated for free expansion without taking into account the rail fastenings and any possible compression in the rail.

The gap to be left when laying rails L metres long at T_0 degrees C. is :

$$\lambda = L \times 10.5 \times 10^{-6} \; (60 - T_0).$$

The fish-plated joints, especially as regards the diameter of the holes drilled in the web of the rails, the diameter of the fish-bolts, and their holes, must be so designed that the rail can contract without being put into tension by the fish-bolts, even at the lowest temperatures it may have to stand.

As gaps much greater than some 20 mm. (25/32″) can hardly be allowed in track run over at high speeds, this formula limits the length of the rail to 24 m. (78′ 9″).

The maximum length on some railways is even less. The *French Nord*, for example, finding that the wear of the rail ends (damaged about the joint) increases with the average gap has reduced the rail length from 24 m. to 18 m. (from 78′ 9″ to 59′ 5/8″).

3. Rules followed when laying rails exceeding 24 m. (78′ 9″) in length.

The use of rails of over 24 m. leads to the rails being subject to compression or tension. This is the case on the *Rumanian, Jugoslav, Czechoslovak* and *Egyptian* State Railways, with their 30 to 36-m. (98′ 5 1/8″ to 118′ 1 1/4″) long rails as shown below.

For temperatures between the lowest and a certain temperature T_1, the rail is put into tension through the fish-bolts.

Between this temperature T_1 and a second limit T_2, it may be supposed to take the length corresponding to free expansion. It may, however, not be able to take this length because of the resistance of the rail fastenings and the ballast, which can reduce the expansion of the rail and put it into partial compression.

We will study this influence in detail later on, when it will be seen to be of relatively little importance for the rails of 30 m. to 60 m. (98′ 5 1/8″ to 196′ 10 1/4″) with which we are dealing.

Between T_2 and the maximum temperature the rail can come against the rails on each side of it and become in compression. The rails therefore should be laid between T_1 and T_2.

The Rumanian State Railways have laid a number of 36-m. (118′ 1 1/4″) rails and are considering lengths of 60 m. (196′ 10 1/4″) fish-plated together with a maximum gap of 20 mm. (25/32″). For rails of 30, 45, and 60 m. (98′ 5 1/8″, 147′ 7 3/4″ and 196′ 10 1/4″) the minimum laying temperatures are : - 10° C. (14° F.), — 5° C. (23° F.), and 0° C. (32° F.) respectively, and the maximum + 45° C. (113° F.), + 35° C. (95° F.) and + 30° C. (86° F.).

The coefficient of expansion is 11×10^{-6}. The range between the temperatures T_1 and T_2 is 55° C. (99° F.), 40° C. (72° F.) and 30° C. (45° F.) respectively instead of 80° C. (144° F.) as stated at the beginning of this chapter. The *Jugoslav State* Railways apply similar rules in the case of their 25 to 30 m. (82′ 1 1/4″ to 98′ 1 5/8″) rails with :

T_2 = + 50° C. (122° F.) } range between T_1 and T_2 :
T_1 = — 15° C. (5° F.) } 65° C. (117° F.).

These Railways use a coefficient of expansion of 11.8×10^{-6}.

The *Czechoslovak State* Railways in the case of rails 20 m. (65′ 7 3/8″) long or over use :

T_1 = — 24° C. (— 11.2° F.)
with a 17-mm. (43/64″) gap.

T_2 = + 30° C. (+ 86° F.)

The *Egyptian State* Railways have laid 1 km. (0.62 mile) of line with 36-m. (118′ 1 1/4″) rails. The rules followed when laying the rails are the same as on the *Rumanian* and *Jugoslav* State Railways with :

T_1 = + 13° C. (55.4° F.)

T_2 = + 58° C. (136.4° F.)
with an 18-mm. (45/64″) gap.

As for the four 36-m. (118′ 1 1/4″) rails on the *French State* Railways, between Sotteville and Rouen on the Paris-Havre line, the temperature variations to which they are subjected are relatively low : + 40° C. (104° F.) to — 15° C. (5° F.). As the maximum rail gap is 20 mm. (25/32″), these rails are never in either compression or tension.

4. Compression and tension stresses in rails when expansion or contraction are entirely prevented.

For each degree centigrade temperature change the total stresses in the whole rail surface increase (or diminish) by $F = SE\alpha$, whatever the length of the rail,

S being the section of the rail in mm²,

E being the modulus of elasticity of

the rail steel, i.e. the ratio of the tensile or compressive stress in kgr./mm² and the proportional elongation or contraction due to this stress.

E can be taken as = 18 000,

α being the coefficient of linear expansion which can be taken as :

$$\alpha = 10.5 \times 10^{-6}$$

F being expressed in kilogrammes.

The area S of the standard French 46 kgr./m. (92.7 lb. per yd.) rail is 5 900 mm² (11.64 circular inches) and for 1° C. rise of temperature the stress F is 1 116 kgr. (1 366 lb. per 1° F.), whatever the length of the rail.

Such is the force developed for example in rails over 24 m. (78′ 9″) in length for each degree rise in temperature above the temperature T_2 referred to above.

The track must be rigid and heavy enough not to get out of line nor lift under such stresses.

When the rails are put into tension by the fish-bolts they are no longer free to expand and contract, and for each degree the temperature drops the tension in them equals in value the compression we have just calculated by the formula :

$$F = SE\alpha.$$

5. Effects of the constraining forces.

These constraints are caused by the :

— the rail fastenings;

— friction between the sleepers and the ballast and of the thrust of the ballast in the recesses between the sleepers;

— friction of the fish-plates on the rails.

When the rail is not put into tension by the fish-bolts nor into compression by contact with the next rail the effect of these constraints is to reduce to some extent the expansion of the rail when the temperature increases and its contraction when the temperature drops.

The gap then closes at a higher temperature than that designated by T_2 above, and the fish-bolts put the rail into tension at a lower temperature than T_1.

Endeavours have been made to take direct measurements of these constraints, but the values obtained varied widely (in the ratio of 1 to 6). Besides, the measurements should not be taken from a section of line specially laid by laboratory staff, nor from a newly laid length of track, but from a section at the limit of wear and weakened by the ordinary maintenance repairs (track not returning properly onto its bed after being jacked up, ballast removed between the sleepers before repacking, etc...).

The least favourable conditions appear to be :

Track consisting of rails, sleepers and fastenings worn down to the limit, ballast loose as after being renewed, i.e. not consolidated by the trains passing over it for a long time, and ordinary repair work in hand (clearing away the ballast between sleepers, jacking up the track, etc...).

The importance of ascertaining the values of these constraints experimentally will be appreciated when it is remembered that the use of long rails depends entirely on the presence of these constraints. Instead of giving in detail the theory of the expansion of rails and the experiments made in connection therewith, we will merely recall the hypotheses on which the calculations are based and the principal conclusions arrived at. From the data recorded we have deduced an important law which we can call : *Law of the previous conditions* —

« The length of a rail depends not only on its temperature but also those in it under its previous conditions. »

Hypothesis 1. — We will imagine all parts of the rail to be at each instant at the same temperature, although it may vary from moment to moment.

Hypothesis 2. — We will ignore the friction due to tightening up the fishplates which, as we know, does not increase the *maximum* tension and compression stresses originating at the middle of the rail in the case of long rails.

Hypothesis 3. — The friction opposing the sliding of the rails on the sleepers by tightening up the fastenings or the sliding of the sleepers on the ballast will be taken into account, the smaller of the two alone being taken into consideration. This friction varies with the wear of the track.

Hypothesis 4. — This friction will be supposed to be distributed uniformly over the whole length of the rail and consequently in proportion to the length affected.

Hypothesis 5. — This friction will be taken as being the same before there is any movement of the rail as when the rail is expanding or contracting.

The friction is designated by p (kgr./per metre of length of rail).

These hypotheses will be examined critically further on.

When the temperature of a rail laid at a temperature T_1 rises, the subsequent expansion does not take place throughout the rail simultaneously.

For an infinitely small length MM_1 of rail such as figure F. 1 to expand, the adjacent layers M_1 J and MJ′ must be pushed away by it and therefore the rise in temperature must have been high enough to develop a compression force at least equal to the two lowest opposing friction forces developed by M_1J and MJ′. It will not expand therefore when the heating up starts, but only after it has attained a certain minimum value.

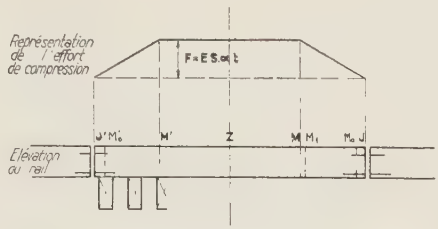


Fig. F. 1.

Note. — Representation... = Representation of the compression stresses. — Elévation = Elevation of the rail.

The nearer MM_1 is to the end J, the lower will be the temperature required to start the rail expanding.

When the temperature of the rail begins to rise the expansion therefore only occurs in the two zones MoJ and M′oJ′ at the rail ends, these zones being very small at first. As the temperature increases, the expansion extends towards the middle of the rail and affects two zones MJ and M′J′ which are the larger the higher the temperature rise.

At a given temperature :

$$T = T_0 - t$$

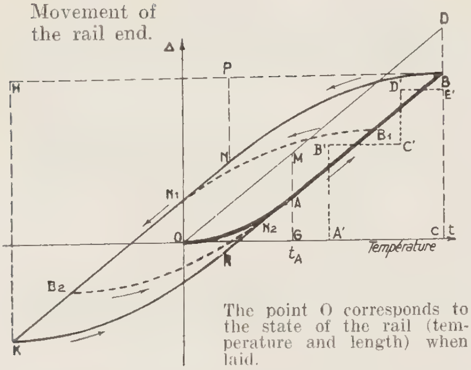
the still unexpanded zone MM′ is subject to a compression force equal to

$$F = SE \alpha t.$$

The compression stress decreases in the zones MJ and M′J′ linearly from F to zero, as the friction has been taken as being uniformly distributed over the length of the rail.

The movement of the rail end J (in terms of the temperature) which would follow the straight line OD (fig. F. 2) of angular coefficient $\frac{L}{2}\alpha$ if the friction forces were nil, takes place according to the arc CA of the parabola :

$$y = \frac{SE}{p} \alpha^2 \frac{t^2}{2}. \text{ (Fig. F. 2).}$$



OD. Straight line = angular coefficient $\frac{L}{2}$ representing the movement of the rail end, supposing there is no friction.

$$OG = \frac{pL}{2\,SE\,\alpha}$$

$$GA = \frac{SE}{p}\,\alpha^2\,\frac{OG^2}{2} = \frac{pL^2}{8\,SE}$$

p = force opposing the free expansion of the rail (in kgr. per metre of rail length)
L = length of rail (in metres).
S = section of rail (in mm²).
E = modulus of elasticity (kgr./mm²).
α = coefficient of expansion of the rail.

BP = 2 OG.
PN = 2 GA.

Fig. F. 2. — Graphical representation of the displacement of a rail end in terms of the temperature.

The point A is reached, the temperature having risen to t_A, when the sections M and M′ (fig. F. 1) have reached the middle Z of the rail. From this moment the expansion continues according to the straight line AB, parallel to OD (fig. F. 2).

The reduction in the expansion through the friction p is shown at all times by the length of the ordinates between OD and OAB.

Let us assume that on reaching the value corresponding to point C (fig. F. 2) the temperature drops. The rail contracts, starting from the ends. The movement of the end this time is a parabola BN with a parametre double that of OA, and extended by a straight line NK parallel to OD. During subsequent heating or cooling, the expansion or contraction of the rail follows parabolic arcs like BN such as B_2N_2 and B_1N_1, but never like OA since the succeeding movements of the rails no longer start from a state of rest, but according to the case, from a state of tension or compression.

Important consequence :
Law of previous conditions.

The length of a rail depends not only on its temperature but on the temperatures in it in its previous conditions.

This observation accounts for the contradictory results obtained by all experimenters who have tried to establish the law of the variation of the length of a rail in terms of the temperature.

Only at the maximum and minimum temperatures has the length of the rail a given length independent from the previous temperature changes (points B and K, fig. F. 2) (1).

The difference in these two lengths (one at the highest, and the other at the lowest temperatures) represents the proper gap at the lowest temperature if the rails are never to be put into ten-

(1) This law accounts for the staff never obtaining the same total value of the gaps in a particular section of the track from one year to another, even if the total amount of gap is reduced to a common temperature. The men usually ascribe the difference to errors in reading the measuremennts or to differences in temperature between the different parts of the rail. We have just shown that these pretended errors of measurement are in fact the result of the « law of previous conditions ».

The philosophical explanation, if we can so call it, of this law is that the friction is an irreversible phenonemon.

The investigations summarised in figure F. 2 show that these differences are simply the result of constraints which oppose free expansion. These constraints cause, on a rising

temperature, a delay in the expansion which amounts to AM (fig. F. 2) in a half rail. When the temperature falls, the contraction is delayed the same amount.

At a given temperature the values of the gaps may differ by

$$J = AM \times 4 = \frac{p\ L^2}{2\ SE}$$

For example : when $p = 500$ kgr. per metre of rail length, the lengths of the rails measuring 18 m., 24 m., and 30 m. at the same temperature can differ by 0.76 mm., 1.35 mm., and 2.1 mm. respectively. In a section with 100 such rails the importance of this difference, which can amount to 76 mm., 135 mm., and 210 mm. respectively, will be appreciated.

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sion nor into compression by their ends.

From the above it can readily be appreciated that the gap λ is the larger the longer the rail length, and the smaller the greater the friction force.

In order to put into figures the effect of these two factors (rail length and friction) we have drawn up the diagram shown in figure F. 3.

This diagram is based on hypotheses

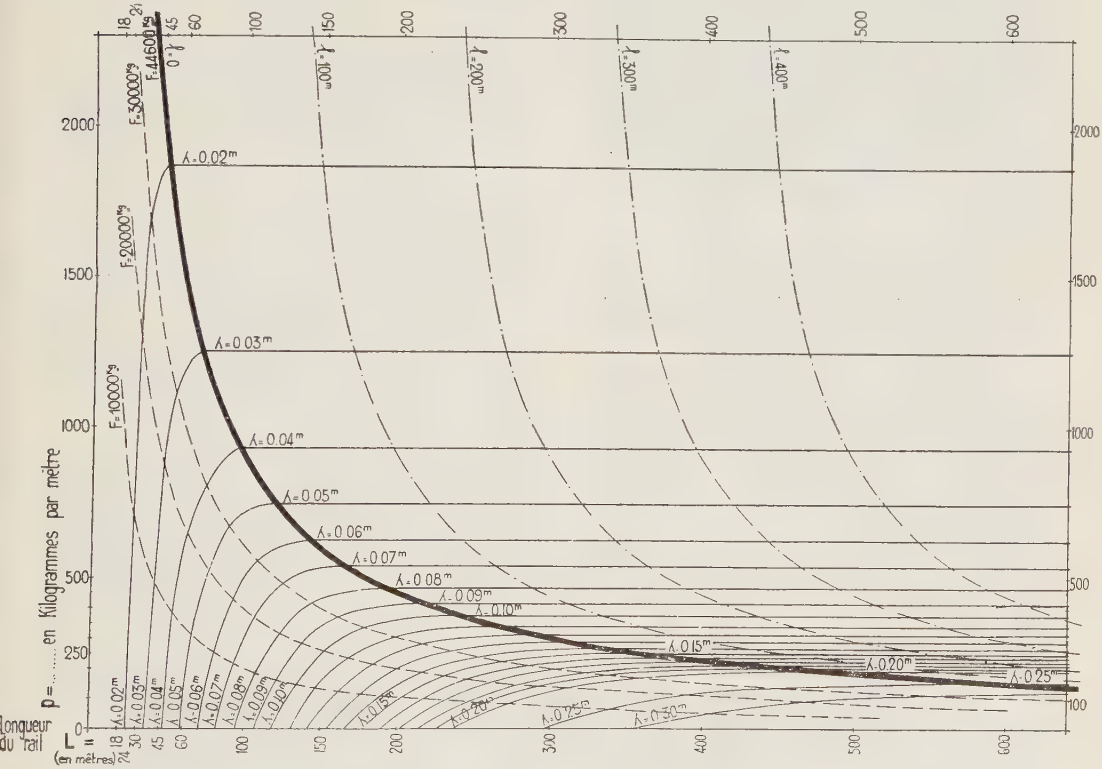

Fig. F. 3. — Chart showing, in terms of the length of a rail (L in metres) and the constraints (p in kgr. per m.) opposing free expansion :

— The gap λ which should exist at the lowest temperature between two adjoining rails.
— The tensile or compression force F in the middle part of the rail at the extreme temperature it can be subjected to.
— The length l of the middle part of the rail where the force F acts.

1 to 5, and also on the following hypothesis No. 6 :

Hypothesis 6. — The rail has been laid at a temperature approaching the arithmetical mean of the extreme temperatures at which the rail *can be*.

The value of the maximum gap in terms of the rail length L (in metres) and the value of the friction p (kgr./m. of rail) can be found from the group of curves in full lines on this diagram.

The maximum tensile or compression force F acting at the middle of the rail is obtained from the group of curves in single-bar lines of figure F. 3.

The length e of the middle part of the rail subjected to this maximum force F is obtained from the group of curves in chain-dotted lines.

As a concrete example, the standard French 46 kgr./m. (92.7 lb. per yd.) rail will be considered. The coefficient of expansion has been taken as :

$$\alpha = 10.5 \times 10^{-6}$$

and the difference between the extreme rail temperatures has been taken as 80° C. (144° F.).

The curves in full lines are for equal gaps and have been drawn from the values :

$$\lambda = 0.02 \text{ m.}$$
$$\lambda = 0.03 \text{ m.}$$

etc., up to = 0.30 m.

The broken lines are curves of equal value of the maximum tensile or compression force F acting in the middle of the rail.

They are drawn for values of F in multiples of 10 000 kgr.

The chain-dotted lines are curves of equal middle lengths of rail subjected to the force F.

Curves have been drawn for :

$$l = 100 \text{ m.}$$
$$l = 200 \text{ m., etc.}$$

The hyperbola

$$pL = SE\,\alpha \times 80° \text{ C.}$$

shown by a heavy line gives the points where the force F is maximum with a value of 44 600 kgr.

This curve divides the plan of the figure into two parts.

In the case of rails with the representative point — function of L and p — above and to the right of this hyperbola the expansion does not reach point A of figure F. 2. We will designate the corresponding zone of the diagram as the zone of parabolic expansion, or simply the parabolic zone.

When this point falls below the curve and to the left, the expansion at extreme temperatures follows the straight lines AB and NK of figure F. 2. This zone of the diagram will be called the zone of linear expansion, or simply « linear zone ».

As can be seen, the *required gap* in the linear zone increases with the length of the rail, and in the parabolic zone is *independent of the rail length*.

The force F increases with L and p in the linear zone, but in the parabolic zone, it has a constant value at all points of :

$$F = 44\,600 \text{ kgr.}$$

Finally, in all parts of the linear zone the length l in which the force F acts is nil, as this force only acts in the middle of the rail. In the parabolic zone this length l is not nil, but increases with L.

6. Critical examination of the hypotheses on which the above study was based.

The simple hypotheses stated above before the calculations are not confirmed in practice. Some of the causes of the difference between practice and theory are as follows :

a) The friction p is neither constant nor uniformly distributed. The measurements recorded give very variable results. This is not surprising as every time anyone has measured a frictional value, no matter of what sort, the values found differ widely. This is the case for example, (ignoring the friction between the track and the ballast) with the tests made to ascertain the friction of brake blocks on the tyres when the values vary widely, and the measurements of the friction of the tyres on the running surface of the rails during hunting, which have given widely differing values.

b) To the friction between the rails and the sleepers, and between the sleepers and the ballast, must be added the thrust of the sleepers on the ballast between them.

This thrust varies extremely widely according to the composition of the ballast, its sharpness, cleanness, etc... In a siding with the ballast completely consolidated (service siding, shunting siding, etc...) this thrust which acts as a brake on the expansion, can be very important.

c) The friction p is relatively great so long as the rail does not move (starting friction), and falls off considerably as soon as movement takes place (moving friction), so that the expansion follows a broken line, such as OA′ B′ C′ D′ E′ instead of OAB of figure F. 2.

d) Then too the resistance of the ballast opposing the movement of the sleeppers is very irregular in time. Ultimately the individual stones in the ballast, from being sharp, become smoothed as the photograph, figure F. 4 shows. The resistance p therefore can fall off considerably after a time. The coach screws too do not hold so well when the holes in the sleepers wear through the wood ageing.

Fig. F. 4. — Broken limestone ballast one angle of which is polished like marble through the rubbing action and the movement of a sleeper, caused by creep and expansion.

e) Tightening up the fish-plates reduces the maximum expansion, consequently great care is required in applying the above calculations and diagrams in practice. However, the following remarks resulting from a study of the diagram can be used as conclusions.

*a*1. — For rails not exceeding a certain length (about 60 m. = 196′ 10 1/4″), the *friction p has very little influence* as regards reducing the expansion. If the rails are not to come into contact at their maximum temperature the gaps must be about the same as if there were no friction. Thus for 30-m. (98′ 5 1/8″) rails the maximum gap would be :

(1) 0.026 m. (1.023″) if p = 0.
0.023 m. (0.905″) if p = 300 kgr./m. (201 lb. p. ft.).
0.022 m. (0.866″) if p = 500 kgr./m. (336 lb. p. ft.).
For 60-m. (196′ 10 1/4″) rails this gap would be :
0.050 m. (1.968″) if p = 0.
0.046 m. (1.811″) if p = 300 kgr./m. (201 lb. p. ft.).
0.042 m. (1.653″) if p = 500 kgr./m. (336 lb. p. ft.).

However, the compression or tensile stresses in the middle of these 60-m. rails will be :

9 000 kgr. (19 840 lb.) when p = 300 kgr./m. (201 lb. p. ft.).

15 000 kgr. (33 070 lb.) when p = 500 kgr./m. (336 lb. p. ft.) when the temperature rises 40° C. (72° F.) above the laying temperature.

New 30 to 60-m. (98′ 5 1/8″ to 196′ 10 1/4″) rails with ordinary fish-plated joints, with a maximum gap of some 20 mm. (0.787″) would come into contact with one another at a temperature only very slightly above that designated by T_2 at the beginning of this chapter, and above this temperature it would be subjected to a compression force increasing by 1 116 kgr. (2 460 lb.) per degree of temperature rise, as we have seen above.

These considerations, we think, supply the reason for certain failures with 50 to 60-m. rails in sidings with widely spaced sleepers and open ballast.

*a*2. — As soon as the rails are long enough to get into the zone of parabolic expansion, i.e. with the ordinary value of p starting from L = 200 to 300 m. (656′ to 984′), the required gap at the ends of the rail is independent of the rail length. This gap is :

0.125 m. (4.921″) when p = 300 kgr./m. (201 lb. p. ft.) of rail;

0.075 m. (2.953″) when p = 500 kgr./m. (336 lb. p. ft.) of rail.

The maximum compression force in the rail is itself independent of L so that in this zone the only effect of increasing the rail length is to increase proportionally the middle part on which the maximum force is exerted.

Consequently if the rails are made longer and longer, the gap at the joints and the force to which they are subjected increased and reach their maximum values for rails about 200 to 300 m. (656′ to 984′) long. These are the lengths which present all the difficulties which have to be overcome when using extra-long rails.

If a track can be laid with 200 to 300-m. rails under practical conditions without transverse deformation occurring during the experiment, such permanent way is equally suitable for rails welded into much greater lengths, as for example 1 km. (0.62 mile).

7. Trial with 1-km. (0.62 mile) rails on the Egyptian State Railways.

The *Egyptian State* Railways are the only ones we are dealing with to use

(1) As regards the value of the force p, the research work made by the Delaware & Hudson Railway may be mentioned. Three sections of extra-long rails, 823 m. (2 700′), 1 350 m. (4 330′), and 2 124 m. (6 970′) respectively, were laid in 1934 and 1935. The results were reported by Prof. Arthur E. Talbot before the American Railroad Engineering Association, and were dealt with in an article by H. Clarke, Civil Engineer of the Delaware & Hudson Railway, in the *Railway Gazette* of the 6th March 1935, p. 447.

Professor Talbot stated in his report that the anchorage force due to the sleepers varied from 45 to 335 kgr. (100 to 740 lb.) per sleeper and per rail.

When the sleeper spacing averages 0.60 m. (2′), the value of p lies between 75 and 560 kgr. (50.4 to 376 lb. p. ft.) These tests, it must not be forgotten, were made with new track, i. e. with track giving the maximum resistance.

very much longer rails than the usual outside tunnels and metal bridges. In August 1935 two rails, each 1 km. long, obtained by welding ordinary 12-m. (39′ 4 1/2″) rails weighing 40 kgr./m. (80.6 lb. p. yd.) were laid in a running road on metal sleepers; the ballast under the sleepers is 40 cm. (15 3/4″) thick.

The rails were thermit-welded alongside the line into 144-m. (472′ 5 3/8″) lengths, which were then laid in position on the track and also thermit-welded together, the temperature of the rail steel being about 48° C. (118° F.).

Nothing untoward has been reported since these rails were put into service.

Expansion devices. — The ends of these long 1-km. rails are fitted with expansion devices allowing a maximum movement of 0.05 m. (2″), all of which, the Egyptian Railways state, is not absorbed by the movement of the rails.

Anchorage. — The track is not specially anchored in any way to the formation.

The value of careful records and observations of such rails and their importance in studying the problem of extra-long rails is obvious.

Conditions under which long welded rails should be tested.

The range of temperature to be covered in service is less than in Europe, where it is 80° (144° F.), so that similar tests ought to be made on European Railways. The tests made by European Systems in sidings, although satisfactory, do not permit of forming any idea of the behaviour of long welded rails under heavy fast traffic. The tests undertaken ought to be made on lines over which trains are worked, but until the track has shown itself able to stand the forces set up by the temperature changes without getting out of shape the lines selected should be those over which the speeds are low, such as the goods lines (1).

The places such rails are to be laid should be selected so as to ensure the temperature variations and insulation being as uniform as possible over the whole length, and the difference between the highest and lowest temperature about 80° C. (144° F.).

The behaviour of the rails should be very closely watched for several years, and after the rail has been firmly anchored to the bed by masonry pillars to prevent creep, the following data should be collected as accurately as possible in terms of the temperatures :

1. the expansions and contractions of the rails at all points in their length;

2. the value of the average friction force p and, if need be, its different values at different points of the rail length;

3. the tensile or compression stresses in the different sections of the rail.

* * *

CHAPTER G.

G-1. — Influence of the expansion of the rails on the stability of the track.

As only a few extra-long rails are in service on the Railways consulted, and as they were laid recently, the Railways have not been able to supply any

(1) There is possibly some risk in these tests as it is not enough just to note the behaviour of the track at the different temperatures. In the absence of some means of continuously learning the resistance of the track to transverse deformation there is danger of the track giving unexpectedly under a train. In more precise phraseology, the coefficient of safety of such track is unknown, nor is it possible to say whilst it still holds if it is not at the limit of resistance, a resistance moreover varying with the degree of wear and the state of repair.

detailed information with regard to the effect of the expansion of such rails on the strength of the track.

It seems that in those parts of extra-long rails in which expansion or contraction movements take place under the effect of temperature variations, i.e. a zone of say 50 to 100 m. (164′ to 328′) from each end, only the rigidity of the track itself (assembly of rails and sleepers) and its weight may be relied upon to oppose transverse deformations. Fastening the rails thoroughly onto the sleepers contributes to the rigidity of the track, but at the same time it makes the rails solid with the sleepers, so that

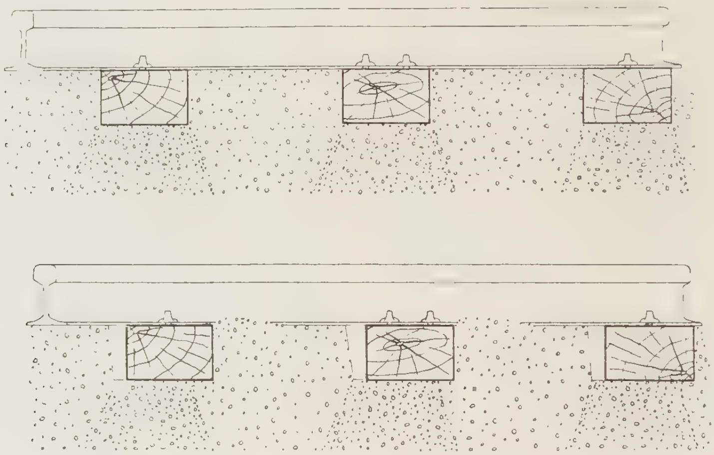

Fig. G. 1. — Slight expansion movements (4 to 5 cm. = 1 9/16" to 2" at most).
The ballast between the sleepers is also moved.

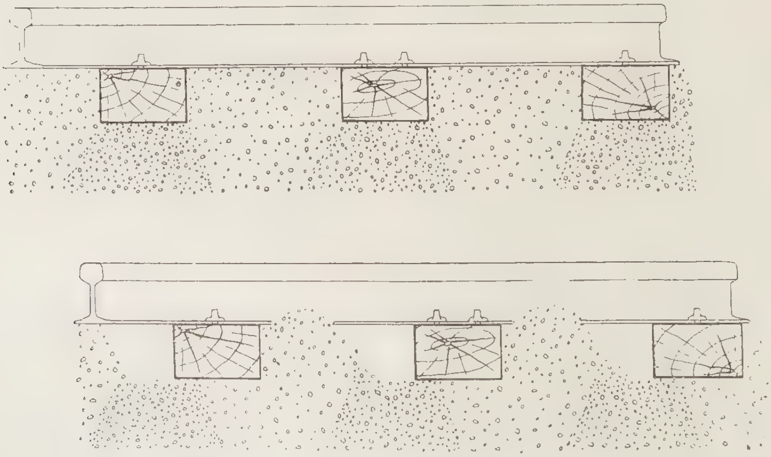

Fig. G. 2. Large expansion movements (10 to 15 cm. = 4″ to 6″, for example).
The ballast between the sleepers is moved.
The sleepers are supported to a large extent by untamped ballast.

they take the latter with them in the course of their expansion and contraction movements.

Now the effect of this displacement of the sleepers is obiously to shift the ballast encased between the sleepers, as is shown by figure G. I. So long as such displacement is not over a certain limit, 4 to 5 cm. (1 9/16″ to 2″), for example, no serious drawback results therefrom as regards the way the track is supported. However, if ampler displacements occur, the sleepers may rest on unpacked ballast (fig. G. 2).

In the two examples of extra-long rails already quoted (*Egyptian State* and *Delaware & Hudson*), the maximum longitudinal movements noted at the ends of these rails were :

Egyptian State : 0.03 m. (1 3/16″) for 1-km. (0.62 mile) rails;

Delaware & Hudson : 0.013 m. (1/2″) for 823-m., 1 350-m. and 2 124-m. (2 700′, 4 330′ and 6 970′) rails.

It is true that the expansion on the latter System was braked owing to the fact that the fish-plates were tightened up strongly enough. Mr. Talbot, in the report quoted above, estimates that the fish-plates transmitted to the adjacent rails a load of as much as 420 kgr./cm² (5 970 lb. per sq. inch) of the rail section.

G-2. — Design of the joints at the ends of extra-long rails.

Such joints must take up the longitudinal displacements of the rails we just mentioned, the effect of such displacements being to create, between two adjacent rails of the same length, at the lowest temperature, a gap equal to twice these displacements.

If the rails are rather short, and the friction opposing their expansion is great enough for the gap not to exceed about 0.02 m. (25/32″), ordinary fish-plated joints can be used.

When the gap exceeds this amount, it appears preferable to use special devices. Such devices are already in use

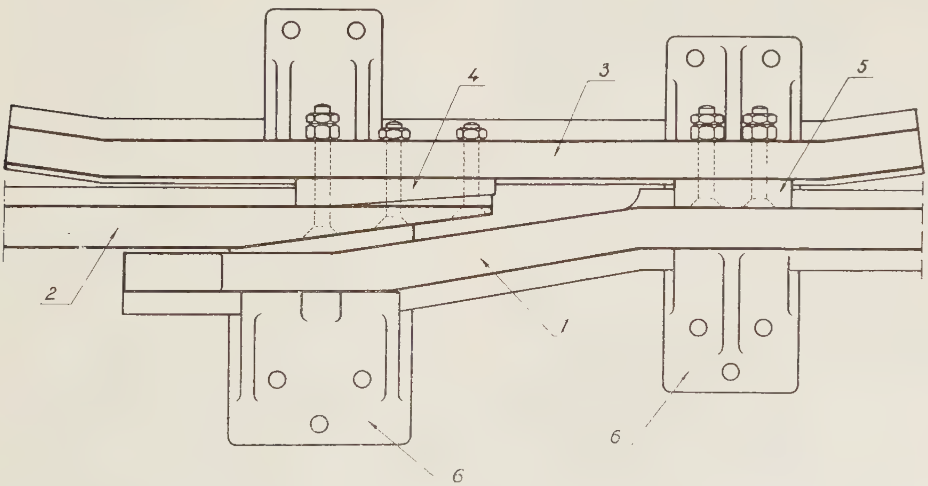

Fig. G. 3. — General layout of an expansion device, *Paris-Lyon-Méditerranée* Railway (France).

Legend:

1. Rail free to move longitudinally when expanding.
2. Fixed rail.
3. Check rail.
4. Block connecting the fixed rail to the check rail.
5. Sliding block maintaining the gap between the mobile rail and the check rail.
6. Chair securing the device to the sleepers.

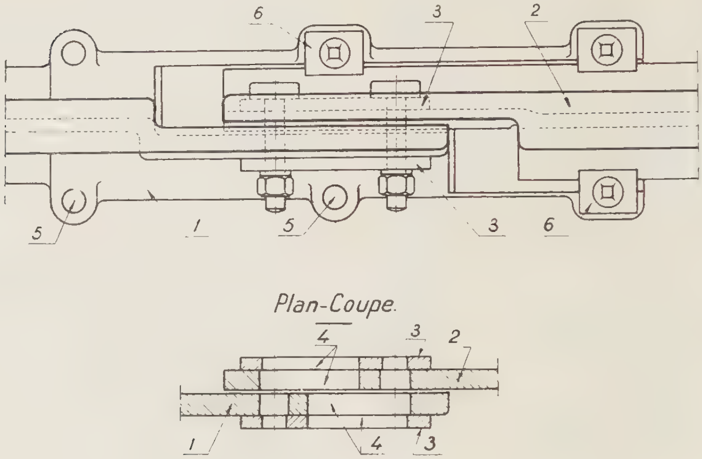

Fig. G. 4. — General layout of an expansion device (*French Est* Railway).

Legend:

1. Slide forming the fixed rail.
2. Rail free to move longitudinally when expanding.
3. Slide plates.
4. Openings allowing the free rail to slide.
5. Holes for coach screws holding the slide.
6. Clips preventing the free rail from lifting.

at the ends of track laid on metal bridges exceeding a certain length. Figures G. 3 and G. 4 are diagrams of two such devices. That of figure G. 3 is based on the same principle as the design of crossings (assembly of point and wing rail), and will take up displacements of 0.018 to 0.02 m. (45/64″ to 25/32″). In the case of all-welded track in which there are no longer individual spots setting up shocks all along the rail, the use of this expansion joint, owing to the unavoidable wear and batter in all constructions including points and wing rails, would reintroduce one such particular spot. The device shown in figure G. 4 does not show the drawback of the preceding type. Besides, it will allow of greater displacements being taken up.

Shocks or reactions cannot, however be entirely avoided when running over this joint, owing to the variations in contour of new and worn tyres which run in turn over the outside part of the rail head.

* * *

CHAPTER H.

H-1. — Making the welds.

1. Where are the welds made ?

Thermit welds can be made either in a workshop or a temporary mobile shop, or on the line itself.

In the first case, the permanent workshop, proper equipment for dealing with the work (picking out rails worn the same amount, etc...) can be provided, the work can be properly organised, and the cost reduced; the men, including the labourers become more experienced, thereby increasing the output.

Then too the welds being made by experienced workmen are also better.

As an example, a description of a shop organised by the *French Est* for thermit-pressure welding is given later on.

In the second case, the carriage charges are less when the mobile shop is located close to the stock of rails to be welded or the place the welded rails are used. A careful investigation should

therefore be made in each particular case to see which method is the cheaper, carriage charges included.

Finally rails can be welded in the track. This case would arise when welding very long lengths (exceeding 500 m. = 1 640′). The work would be started by welding several rails together, to make 500-m. lengths which are not too long to be carried on flat wagons, two per wagon. These 500 m. lengths would then be welded together in the track itself. It is customary to weld rails together in sidings without lifting them.

This is the method used by the French Nord for some 30 000 thermit-fusion welds made in sidings.

In the running track, the rail ends have to be cropped if the track is to carry fast heavy traffic, so that the rails must be taken up before welding.

An example of a thermit-welding shop.

The arrangement of such a shop depends on the space available, but also on keeping down to the minimum the handling operations which are costly, and largely govern the daily output.

Figure H. 1 shows the layout of a shop in which 25 finished welds are made per day with 11 men. The equipment includes a setting out table 14 m. (45′ 11″) wide and 48 m. (157′ 5 3/4″) long located between two parallel roads. This table consists of old rails set 4 m. (13′ 1 1/2″) apart, carried on wood blocks. The top of the table is level with the floor of the trucks used in the shop, i.e. 0.35 m. (25 3/4″) above rail level. The rails to be welded are brought in on a standard-gauge track, and are lifted on to the table by a steam crane.

The welded rails are taken to the planing machine on a 60-cm. (1′ 11 5/8″) track.

A gantry crane serves the whole shop and is used to place the presses employed in connection with the welding.

2. Who makes the welds ?

The thermit welds to be used on the main lines, whether pressure or fusion, are made in many cases by contractors, specialising in this work, either in their own shops or in the railway shops, or on the track.

When contractors are employed, they supply the materials, equipment, and technical staff. A shop, for example, can be staffed by a specialist and a number of non-specialist workmen supplied by the railway.

Welds made by contractors are guaranteed usually for a year, that is to say if a weld breaks within a year the contractor either remakes it free of charge or meets a guarantee.

Pressure or fusion welds of rails to be used in sidings are made by the railways themselves in many cases, the equipment being generally carried in a travelling workshop which can be taken close to the place where the welding is to be done.

The materials used in making the welds are bought from the contractors ready for use.

Up to the present, electric flash welding has always been done in a shop specially equipped for the purpose, in the countries with which we are dealing. Some of the shops belong to contractors, others to the railways *(French Nord)*. In the latter case the welding is done by the railway staff. A travelling shop may be envisaged (diesel engine, alternator, transformer and welding machine). The cost would be high as it would include that of the generating plant, whereas in a proper shop current can be taken from the industrial supply.

3. Technical specifications and inspection tests.

No railway consulted mentions technical specifications or specifications for passing the welds.

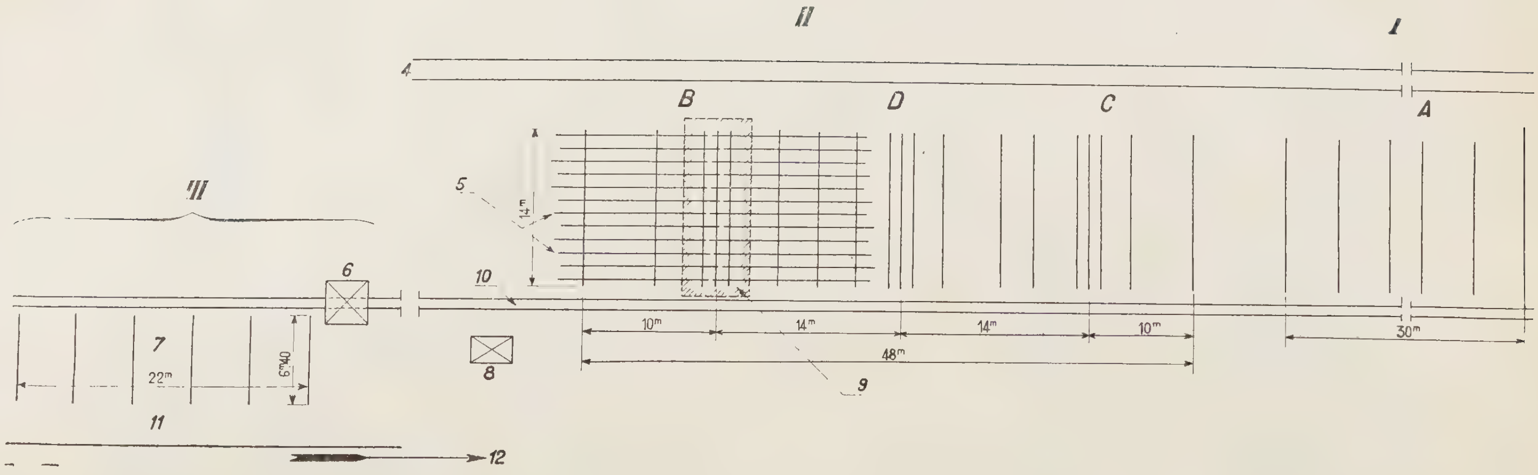

Fig. H. 1. — Layout of a thermit-pressure welding shop.

Legend :

A. Stock of rails to be welded.

B. Welding section.

C. Section preparing the rails for welding (rails 18 to 22 m. = 59' 5/8" to 72' 2 1/8" long after welding).

D. Section for 48-m. (157' 5 3/4") rails.

4. Standard-gauge line for the travelling crane for carrying the rails from section A to sections B, C or D.

5. Rails for welding.

6. Shaping machine for cleaning up the weld.

7. Hand planing (finishing).

8. Shelter for the moulder.

9. Covered mobile gantry crane with travelling block and tackle serving sections B, C and D.

10. 60-cm. (1' 11 5/8") track for the trolleys carrying the welded rails to the planing section III.

11. Stock of welded rails.

12. Standard-gauge track conveying the welded rails to the sawing and drilling section.

The rails to be welded are craned from the stock A to section B or C for rails to be 18 to 22 m. after welding, or to D for 48-m. rails. After welding and annealing, the welded rails are conveyed by the 60-cm. track to section III where the weld is machined and finished by hand planing. The rails are then cut to the desired length and drilled.

As a rule there is no systematic testing of welds before laying the welded rails in the track.

The railways, however, select some of the welds and subject them to various tests (impact — hardness — macrographical and micrographical examinations — repeated bending — static bend) mentioned above.

These different tests form an excellent method of investigation for improving the welding. Methodical tests of this kind resulted in the welds being heat-treated (annealing in the case of welds of ordinary non-hardened rails and hardening welds in rails already hardened during manufacture).

A drop test might be imposed when passing welds as by the *French Railways* for new rails [drop test with 300 kgr. (660-lb.) tup falling 4.60 m. (15′ 1 1/8″) on the rail placed head downwards, i.e. in tension, the rail head being notched as shown in figure H. 2].

Similarly, the weld could have a notch milled across it, but so far no railway has imposed such a test when letting contracts for welding.

As a matter of fact, the difficulty is in the penalty to be inflicted for failure to meet the tests. The batch of welds from which the test weld has been selected cannot be rejected as the railway supplying the rails would be by far the more heavily penalised. It would be possible of course to impose a penalty by a reduction in the price paid. But the question of using the rails would then demand examination, as the use of doubtful rails might be considered as affecting safety. This difficulty might be overcome by using the rails in a section with light traffic and requiring them to be specially watched; this method has not been adopted so far.

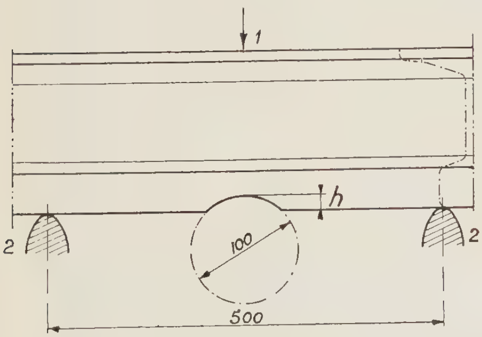

Fig. H. 2. — Piece of new rail subjected to a drop test, head of rail in tension (underneath).

Legend:

1. Point of impact of 300-kgr. (660 lb.) tup.
2. Fixed supports.

h depth of milled notch (14.5 mm. = 9/16" for standard French rails weighing 46 kgr./m. = 92.7 lb. per yd.).

4. Instruction of the staff.

The staff engaged in the actual welding usually go through a course in a welding school or in a works engaged in welding work. The men directing and supervising the welding and the man in charge of the test laboratory usually have followed an educational course in a welding institution and frequently possess the diploma of welding engineer.

* * *

H-2. — Welding costs.

The cost of a thermit-pressure welded joint varies with the conditions under which it is made.

In a fixed shop or a temporary mobile shop, specially fitted up for making large numbers of welds, the cost is less than when the welds are made in small numbers near the place the rails are to be used.

Welds of rails to be used in tunnels, carried out nearby, are still more costly owing to the safety measures to be taken to protect the staff.

Thermit-fusion welding is about 20 % cheaper than thermit-pressure.

Finally, the heat treatment (annealing) of the welded joints is not expensive and only increases the cost by about

10 %. As the quality of the weld is much improved, the practice can be recommended.

Even at the lowest, the cost of a thermit weld is still 3 or 4 times that of a fish-plated joint (including supplying, carrying and fitting the small details such as fish-plates, bolts, etc.). However, when the saving in the permanent way maintenance costs is taken into account, welded joints as we shall see later on, do effect an economy.

Electric welding is very cheap, occasionally less than half that of an ordinary fish-plated joint, but the cost of writing off the first cost of the equipment, amounting to several hundreds of thousand francs, must be added.

Saving in maintenance. — All railways agree that the maintenance of the rail joints forms a large part of the total cost of maintenance. Some engineers estimate it at 45 %.

Joints between rails of different section are even more costly than the others.

It is easy to understand that a joint is expensive to maintain : it requires more packing than the running lines, it has to be lined up again, especially on curves, to avoid angles which generally start at the joints, provision has to be made for expansion (slackening and tightening the bolts twice a year), the fish-plates must be lubricated to prevent rust, which corrodes the fishing surfaces, the worn fish-plates have to be replaced (reformed fish-plates used), etc...

In tunnels welding gives even greater savings than in the open as the cost of the repairs is so much higher through the extra look-out men and lighting required and the difficulty of bringing up materials, etc...

Although welded joints are undoubtedly an economy, the value of the savings is difficult to calculate as there are so many factors which change the bases of comparison, as in all matters in connection with railways.

The *Jugoslav State* Railways, however, have succeeded in working out this saving sufficiently closely. They bring into account the cost (supplying and laying) of two welded and two fished joints; the average life of the rails in the running roads (20 years in the open and 7 in the tunnels); and the average cost of maintaining the fished joints which they estimate as the equivalent of 3 m. (9.84′) of track in the open and 9 m. (29.5′) in tunnels. In this way the thermit-pressure weld shows a net annual saving of 2 francs per pair of welded joints in the open, and 2.50 francs in tunnels [1].

Then too the fewer joints probably reduce the tyre wear which, while difficult to figure, is nonetheless very real.

* * *

CHAPTER I.

I-1. — Application of welding to the manufacture of points and crossings.

As has been seen above the practice of welding rails by the thermit or electric flash processes has grown in recent years.

The same cannot be said of welding points and crossings, as this can only be done by arc welding or gas welding.

As is known, these two methods have only been perfected and used in constructional work quite recently. There has been some fear too as to whether this kind of weld would stand repeated shocks. This explains the delay in applying welding to points and crossings, either in their manufacture or for repair work.

(1) These prices were supplied by the *Jugoslav State* Railways in French francs.

In order to avoid confusion in the names of the different parts of points and crossings, figs. I. 1 to I. 4 are diagrams of a simple pair of points, a half pair of points, a crossing and slip

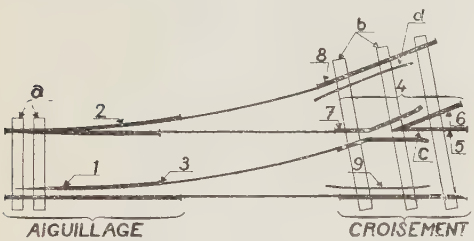

Fig. I. 1. — Plan of a turnout.

Legend:

1. Switch.
2. Stock rail.
3. Heel joint.
4. Acute crossing.
5. V-piece.
6. Splice rail.
7. Wing rail.
8. Outer running rail.
9. Check rail.

a Sleeper supporting the switch.
b Timbers supporting the crossing.
c Gap between point rail and wing rail.
d Gap between outer running rail and check rail.

Note: Aiguillage = pair of points.
Croisement = crossing.

points, with the names of the principal parts.

In running roads run over at high speeds by heavy engines, very few welded parts are used in points and crossings. The railways consulted generally use welded points and crossings in sidings.

Welding is used mainly:

a) to weld to a base plate the different parts of a crossing (figure I. 5 is a cross section on *xy* of figure I. 3), these parts, made of rails, being machined by planing;

Fig. I. 2. — Plan of a half switch.

Legend:

3. Heel joint. The blade is sometimes fitted at this end with a pivot which turns in a spherical bearing formed in the heel chair.
16. Sliding plate or sliding chair.
17. Bearing stud.
18. Heel chair.
19. Distance piece at the heel.
21. Bearing plate (used in certain welded switches).

b) to weld the cross ties to the rails which they keep to gauge (the section *a-b* of fig. I.6 corresponds to a cross section *st* of figure I. 4);

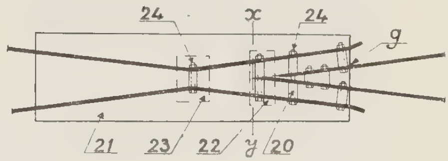

Fig. I. 3. — Plan of an acute crossing for a turnout, for a diamond crossing, for slip points.

Legend:

20. Distance piece.
21. Bearing plate.
22. Plate under V-piece. } These plates are not provided in crossings when there is a bearing plate.
23. Plate under cranked rails. }
24. Assembly bolt.

c) to weld the stock rails to a bearing plate which at the same time forms the sliding chair of the points (fig. I. 7) or to weld the sliding chairs (fig. I. 8) themselves to a bearing plate.

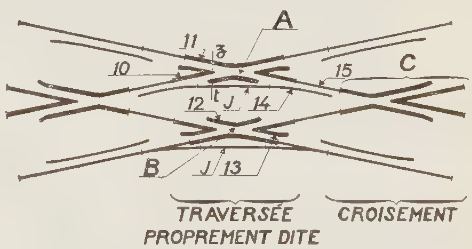

Fig. I. 4. — Plan of single slip points.

Legend:

A Obtuse crossing.
B Obtuse crossing.
C Acute crossing.
10. Nose of obtuse crossing.
11. Bent rail.
12. Check rail.
13. Wing rail.
14. Switch.
15. Stock rail.
J Junction rails.

In the diamond crossing, the junction rails J and the switches 14 do not exist; the switch stock rails 15 are replaced by ordinary rails.

Note: Traversée proprement dite = obtuse crossing proper. — Croisement = acute crossing.

The following are the resulting advantages :

1. The assembly does not become slack, whence cheaper maintenance (less tamping or shovel packing and less frequent tightening up the fastenings);

b) the wear of the different parts such as the nose and wing rails, of acute crossings, timbers supporting the crossings, distance pieces, etc... is slower, and this lengthens the period between renewals.

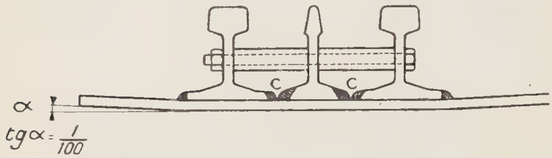

Fig. I. 5. — Cross section of an acute crossing welded on a bearing plate.

Legend :
C Electric-arc weld made after chamfering the edges of the rail foot.

2. The points and crossings are repaired more easily, as the running surfaces of the different parts (acute crossing nose and wing rails, stock rails) can be built up by arc welding as explained in the next chapter. With ordinary points it is also necessary, in some cases, to replace such parts as the

Plan.

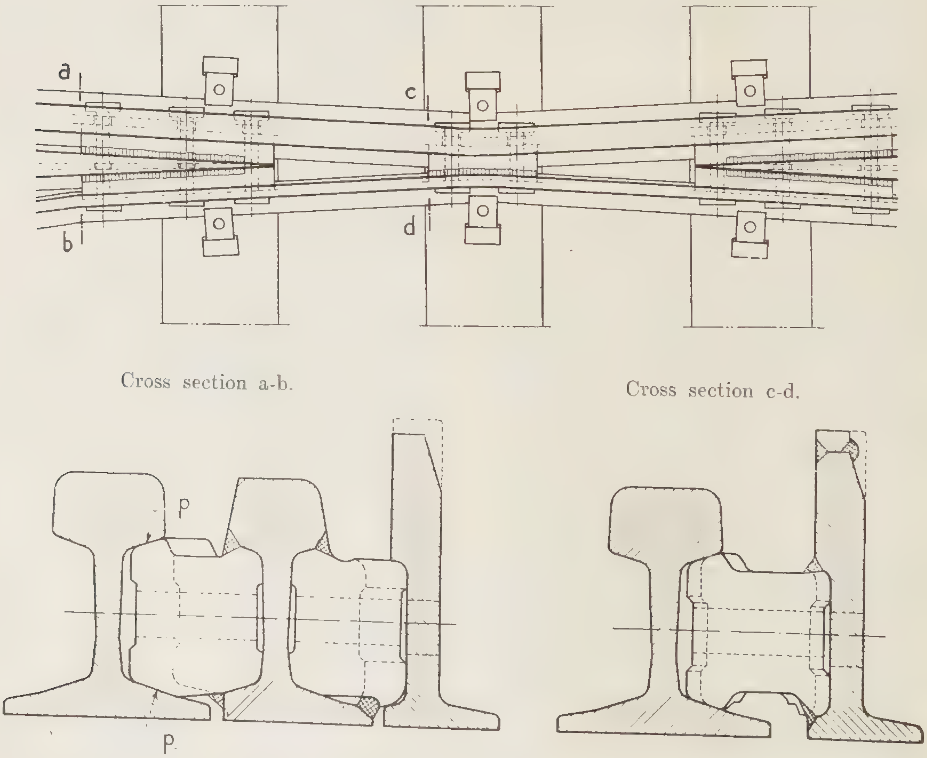

Fig. I. 6. — General arrangement and details of an obtuse crossing (*Czechoslovak State* Railways).

distance pieces, plates, and assembly bolts. Besides which, as the fishing surfaces when worn as shown at *p*, in figure I. 6 cannot be restored by welding, even with new distance blocks, the assembly would not be perfect.

The *French Nord, Czechoslovak State, French State, Alsace-Lorraine* and *Rumanian State,* are the only railways to report using welded details in their points and crossings.

The *French Nord* is the largest user, having more than 2 000 welded points and crossings in service.

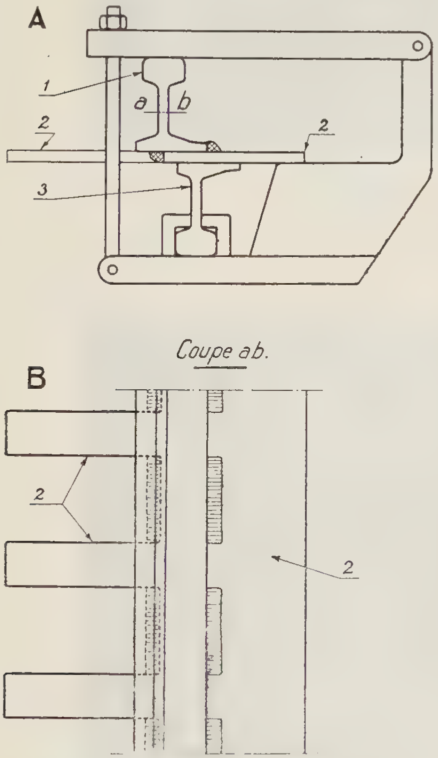

Fig. I. 7. — Welding a stock rail on a bearing plate.

Legend:

A Preparatory set up.
1. Stock rail.
2. Stock rail bearing plate acting as sliding plate for the blade.
3. Jig rail.
B Plan view of the stock rail welded on the plate.

We will describe first of all what has been done on this railway.

I. — French Nord.

1. *Description of the work done.*

The *French Nord* has been fabricating details of points and crossings by welding since 1929. The parts assembled by

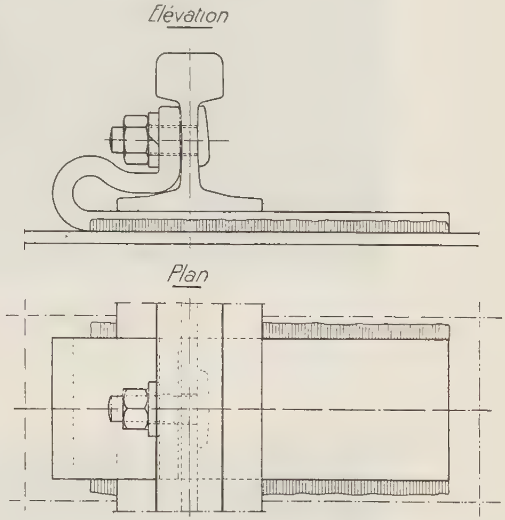

Fig. I. 8. — Sliding chair.

welding are : acute crossings (fig. I. 9) and obtuse crossings for single slips (fig. I. 10), check rails welded to bearing plates (fig. I. 7).

These points and crossings, in which the rails are directly welded to the steel bearing plates, are used in holding sidings, harbour roads, locomotive depots, and station lines not run over at speed.

Photographs figs. I. 8^{II} to I. 8^{V} are views of points fabricated in this way.

For use in high-speed lines the *French Nord* uses a type of switch in which the stock rail is bolted to the pressed steel chairs (fig. I. 8) welded to a bearing plate.

The use of welding has made it possible to redesign the acute crossings,

Fig. I. 8II. — Switch in which the stock rails are welded to their bearing plates (*French Nord* Railway).

This photograph is of a switch as shown diagrammatically in figure I. 7.

Fig. I. 8III. — Acute crossings with the rails welded to the bearing plate (*French Nord* Railway).

This photograph shows a crossing of the design shown in diagram form in figure I. 9.

Fig. I. 8IV. — Obtuse crossing with the rails welded to a bearing plate (*French Nord* Railway).

This photograph shows a crossing of the design shown in diagram form in figure I. 10.

Fig. I. 8V. — Group of points and crossings with welded assemblies at the entrance to a locomotive depot (*French Nord* Railway).

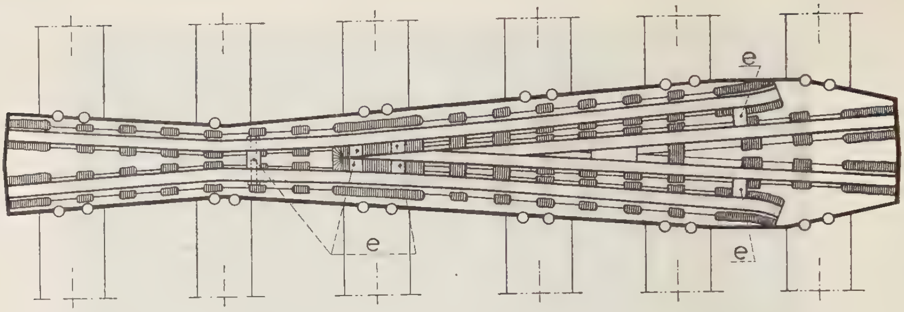

Fig. I. 9. — Layout of a welded acute crossing (*French Nord* Railway).
e Steel tube distance pieces.

for example for the noses the *Nord* special 43-kgr./m. (86.7 lb. p. yd.) rail with 97-mm. (3 3/16″) foot has been used in place of the 45 kgr./m. (90.7 lb. p. yd.) rail with a 135-mm. (5 5/16″) foot, so as to be able to weld in the gap between the nose and the wing rails.

With the same object, the cast iron distance pieces have been replaced by steel tube spacers (*e* of fig. I. 9). Bolts and stays have to be retained so as to keep the parts in place when welding and stop the gaps closing up through the contraction the weld causes.

The foot of the crossing nose and wing rails is chamfered off (*e* of fig. I. 5) to facilitate the welding in the gaps.

In the first welded points fabricated the noses were welded to bearing plates shorter than the nose rails. Some breakages occurred in line with the last welds on the bearing plate (*g* of fig. I. 3). The bearing plates were then extended to the end of the rails. (In the few cases where the bearing plate cannot be lengthened to the end of the rails satisfactorily, the rail is strengthened by a pair of fish-plates in line with the last weld (*f* of fig. I. 10.)

2. *Welding processes.*

The *French Nord* as a rule welds with coated electrodes. The diameter is 5 mm. (3/16″) with a thin coating. As an experiment a number of units have been welded by the atomic hydrogen process. The burner is too large for the gaps in the noses, so that the process had to be limited to welding the stock rails.

Tests have been made with a view to comparing spot welding with arc welding which gives added metal.

Drop tests showed that spot welding was unsatisfactory. No heat nor mechanical treatment of details in points and crossings has been found necessary after welding. In particular hammering the weld whilst hot does not appear desirable.

3. *Carrying out the work.*

Some details are given below on (1) setting up, and (2) actually making the welds, in the case of :

a) acute crossings :

b) switches.

a) Acute crossings :

(1) *Setting up.* — The parts to be welded together into crossings and single slips are first of all put together with stays and bolts in the ordinary way. The pieces are then laid out on 10 mm. (3/8″) thick steel bearing plates which have been cut by oxy-acetylene blow lamp, and the whole secured to a base built up of very rigid rolled sections by heavy bolts and bearings (fig. I. 11).

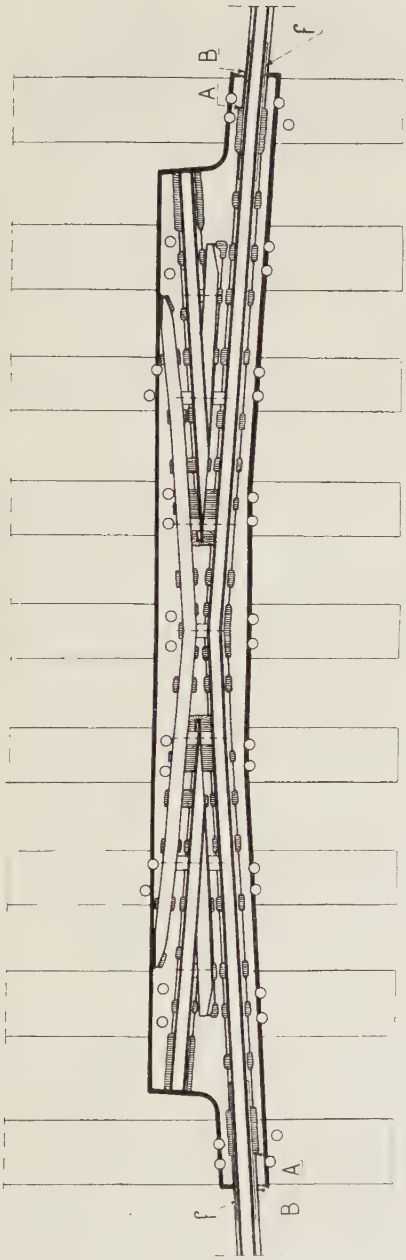

Fig. I. 10. – Layout of a welded obtuse crossing (*French Nord* Railway).

Note: A. Limit of rail foot welding. — AB. Part of rail not welded to the bearing plate. *f.* Safety fishing.

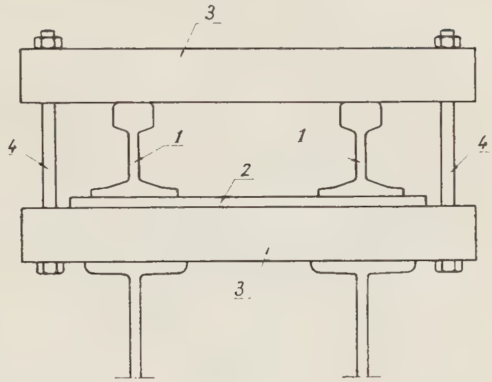

Fig. I. 11. — Preparatory set up for welding an acute crossing.

Legend:

1. Wing rails of the crossing.
2. Bearing plate.
3. Support.
4. Clamp bolt.

The whole assembly is also given a slight reverse camber longitudinally to make good the contraction of the welds as mentioned further on. The amount of camber is determined by trial and error; it is a conditioned by the length of the weld fillets and by the rigidity of the whole assembly.

(2) *Arc welding.* — The weld fillets are laid in the usual manner in two successive runs (fig. I. 12). They are 80 mm. (3 5/32″) long and 120 mm. (4 23/32″) apart, except in line with the nose, where the fillets are continued about 400 mm. (15 3/4″), and the ends

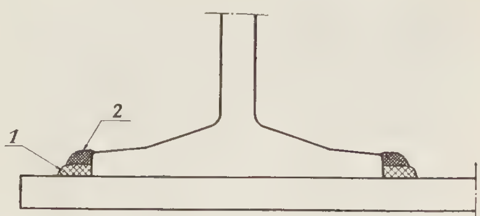

Fig. I. 12. — Two-run weld of a crossing rail foot on the bearing plate.

Note: 1-2. First and second runs.

of the rails, where they are about 200 mm. (7 7/8″) long (fig. I. 9).

b) *Points :*

(1) *Assembly.* — The stock rails are welded together in different jigs from the previous ones.

The stock rail should overlap the bearing plate between the part over which the blade slides (fig. I. 7) sufficiently for the fillets between the rail and the plate not to interfere with the blade going home against the stock rail.

The stock rail is first of all bent cold in a press, both vertically and horizontally, to compensate the curvature arising from the contraction of the welds. It is then put onto the bearing plate previously cut out by blow lamp and held down by clamps and a piece of erecting rail (point 3, fig. I. 7) bent like the rail to be welded.

(2) *Arc welding.* — The fillets are run as in the acute crossings, but continuously on both sides, the full length of the bearing plate over which the blade slides (see section *a b*, fig. I. 7). When the blade slides over special sliding plates (or chairs fig. I. 8), these plates or chairs are welded in advance to the bearing plate.

4. *Contraction of the metal during cooling.*

During cooling the parts contract, and get out of shape, by twisting or bending.

For example a section 4.10 m. (13′ 5 7/16″) long, (such as the nose of a crossing) bends some 25 mm. (1″) measured on the longitudinal vertical plane. This deformation is corrected by bending the rail in the opposite direction the same amount before welding.

A fillet as made by the *French Nord* bends in the transverse direction the 10-mm. (13/32″) thick bearing plate to an angle of tan. $\frac{1}{100}$ (fig. I. 5).

This deformation is negligible on the outside edges of the plate which only extends past the nose some 50 mm. (2″). Inside the nose, however, the gaps would be reduced in width if the correct distance between the nose and the wing rail had not been maintained by the steel tubular distance pieces (part *e*, fig. I. 9).

Owing to the parts being held firmly in the jig and to the nose rails being symmetrical, there is no deformation in the alignment of the rails of the acute or obtuse crossings in the horizontal plane.

This is not the case with the stock rails, where the transverse distances between the inside and outside welding fillets vary.

Any setting needed is done by local heating with the oxy-acetylene blow lamp, and cooled with water as soon as the bearing plate is red hot.

Service breakages and defects. — On some of the welds of parts in points and crossings, made in the early days, the welds partly tore away, but not sufficiently to prevent the points and crossings remaining in service.

The technique of this kind of welding has now been thoroughly perfected, and the *French Nord* no longer has any trouble in practice.

This railway reports having removed 15 defective parts out of 2 000 in service during the last six years, which includes the experimental period.

5. *Cost price.*

The *French Nord* fabricates all its points and crossings in the Moulin-Neuf shops and finds that if the cost of an acute crossing built up in the usual way is represented by 1 (supply and installation in the track) the price of a welded crossing is 1.5, and that of the cast manganese crossing, so far considered the only type better than the ordinary built up crossing, 4.

6. Carrying out the work and training the staff.

All welding in connection with the fabrication of points and crossings is done by the railway in its own shops.

The head of the shop holds the diploma of welding engineer. He has trained the foremen who in turn train the workmen.

Close contact is maintained with outside specialists.

II. — Czechoslovak State Railways.

1. Description of the work carried out.

So far this system has not fabricated any complete points and crossings, but has introduced welding in manufacturing points and acute crossings to simplify the construction and above all to strengthen it.

For example, the pivot has been welded to the blade heel (fig. I. 13). In addition the plates over which the blade slides and the bearing for the holding down clips and the stock rail (fig. I. 14) are welded to the metal sleepers.

In the acute and obtuse crossings, the unit is stiffened by welding the distance pieces to the nose rail or to the stock rail.

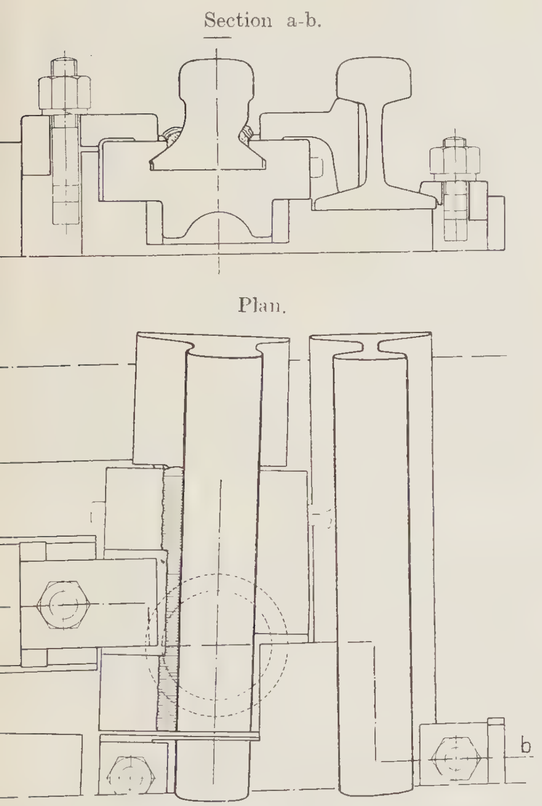

Fig. I. 13. — General arrangement of a pivoted blade heel (*Czechoslovak State* Railways).

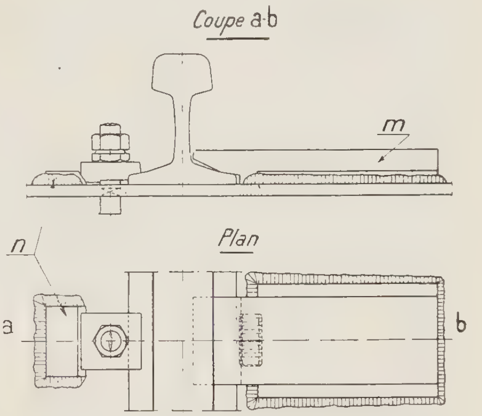

Fig. I. 14. — Fastening of a stock rail to a metal sleeper (*Czechoslovak State* Railways).

Note:
m Sliding chair of the blade.
n Bearing block of check rail holding down clip.

The *Czechoslovak State* Railways have laid in their lines 221 points and crossings reinforced in this way by welding, 218 of them being in lines over which express trains run.

2. Welding processes.

Arc welding is the process used.

3. Tests and checks.

No systematic tests of the welds have

been made, but before using such points and crossings generally, mechanical tests have been carried out, going as far as tearing away the welded bearing plates.

The *Czechoslovak State* Railways have found that the steel sleeper is deformed before the welded plates tear away.

The welded points and crossings are giving satisfaction, maintenance costs being lower than with the old riveted and bolted types.

4. *Breakages and defects.*

Up to the present there has been only one breakage, the blade breaking near the heel bearing, to which the blade is fixed by two welds. It has not been possible to ascertain the cause.

5. *Carrying out the work.*

Welding in connection with points and crossings is done by the trade in its own shops and with its own staff.

III. — French State Railways.

1. *Description of the work.*

This system has laid 5 acute crossings with the parts welded to a bearing plate, in sidings in Sotteville station, near Rouen. The construction is on the same lines as that on the *French Nord.*

The welding was done with the electric arc (added metal).

2. *Breakages and defects.*

One defect has been reported : the welding of the rail foot to the plate came away, but the reason has not been discovered.

3. *Cost price.*

The *French State* Railways find that points and crossing welded to a sole plate cost twice as much as when assembled in the ordinary way.

4. *Saving in maintenance.*

The saving in tamping, shovel packing and tightening up the fastenings is about 25 %.

5. *Carrying out the work.*

The welding has been done by a contractor specialising in this work with his own staff.

No guarantee was required as the work was regarded as experimental.

IV. — Alsace-Lorraine Railways.

1. *Description of work done.*

This railway continues to use the ordinary built-up construction which it strengthens, however, by a run of welding between the rail foot and the thick bearing plate.

This work is done for example when the noses and wing rails are being built up by electric arc welding.

14 acute crossings strengthened by welding in this way have been laid in Strasbourg Central Station.

3 new acute crossings welded to their bearing plates have been laid in the Thionville shed.

The *Alsace-Lorraine* have not reported any breakage or other defects of the points in service.

The ballast under acute crossings welded to bearing plates requires less frequent packing, than with the ordinary built up crossing, as the hammering due to play in the parts is practically eliminated.

2. *Carrying out the work.*

All welding is done by the railway staff and on the track itself without interrupting the traffic.

Welders have been trained by working in a gang of experienced welders under the control of a specialist.

V. — Rumanian State Railways.

This railway has one all-welded acute crossing in the running road of the Bu-

charest-Jimbolia line. It has given no trouble and has stood up better than the ordinary built-up crossing.

VI. — Aciéries de la Chiers.

The « Aciéries de la Chiers » (Meurthe-et-Moselle, France) built as an experiment a number of acute crossings from rolled 12 % manganese steel rails. The rails were planed and then arc-welded together.

Such rails take much longer to machine and cost much more than ordinary rails.

The points and crossings are intended to carry the very heavy slow traffic inside the steelworks : points and crossings in ordinary steel wore away quickly.

The « Aciéries de la Chiers » hope to obtain as good results as with the cast manganese crossings and avoid the inherent defects of castings (internal stresses, segregation, piping and moulding defects).

The rolled manganese steel used in this crossing is not heat-treated. Figure I. 15 shows the method of construc-

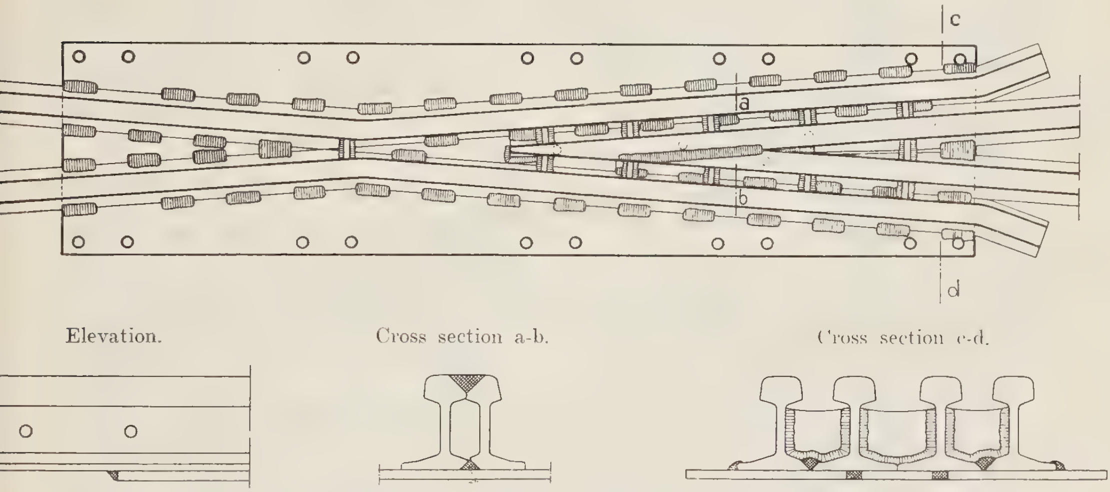

Fig. I. 15. — General arrangement and details of an acute crossing welded to a bearing plate (Manganese steel rails rolled by the *Aciéries de la Chiers*).

tion (as a whole and in detail). The distance pieces are made from 15-mm. (5/8″) thick plate arc-welded into position and the foot of the rails is welded at intervals on a large 15 mm. (5/8″) thick plate.

* * *

I-2. — Use of welding in connection with metal sleepers.

Some railways repair metal sleepers by welding, the *Rumanian State*, for example, using the electric arc process.

The *Czechoslovak State* Railways are welding the bearing plates to the sleepers; 4 000 sleepers dealt with in this way are in use on lines over which express trains are run (fig. I. 16).

The advantage of using welding in this way is that it does away with the fastenings holding the bearing plates to the sleepers, and as there are no fas-

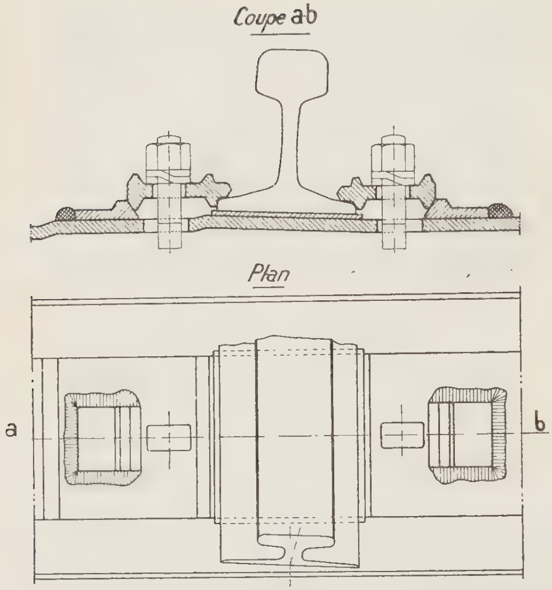

Fig. I. 16. — Welding rail holding down clip bearing blocks metal sleepers *(Czechoslovak State* Railways).

tenings to tighten up, the track is not disturbed and the cost of maintenance is appreciably reduced.

In the same way, the sliding chairs and the supports of the rail clips have been welded to the sleepers (fig. I. 14).

Worn metal sleepers can also be repaired by welding; not only minor repairs but large portions of the sleepers can be renewed.

The worn parts are cut out with the oxy-acetylene blow lamp and replaced by usable parts out of other sleepers. Arc welding is the process usually resorted to.

The *Rumanian State* Railways report the use of arc-welding for repairing metal sleepers, but give no details as to the extent of the repairs done.

* * *

CHAPTER J.

Building op worn details in points and crossings and rail ends in the running roads.

I. — Points and crossings.

1. Description of the work done.

A certain number of railways, either as a trial or as general practice, build up worn parts in points and crossings of the built up type by welding. Thus, the *French Nord* is able to deal with 1 000 crossing noses each year.

These crossings are usually in sidings and run over at low speeds, but there are a number on the main lines over which trains may run at high speeds.

The number of so repaired crossings reported is as follows :

Rumanian State : 3 in high-speed main lines;

Czechoslovak State : 16, 4 of which in high-speed main lines;

French Railways :

Nord	1 800
Alsace-Lorraine	300
State	30
Paris-Lyon-Méditerranée	19
P. O.-Midi	22

The parts built up in this way are the acute and obtuse crossing noses and the wing rails. The wear on these parts, measured by the maximum thickness of metal deposited to bring the running faces back to the original dimensions as shown in figure J. 1, as reported by the *P. O.-Midi* Railway, reaches 18 mm. (11/16″).

On the *French State* points and crossings worn up to 15 mm. (19/32″) but in good order as regards fastenings, etc., have been built up by welding but it is thought the limit should be 8 mm. (5/16″).

It is only profitable, in fact, to build

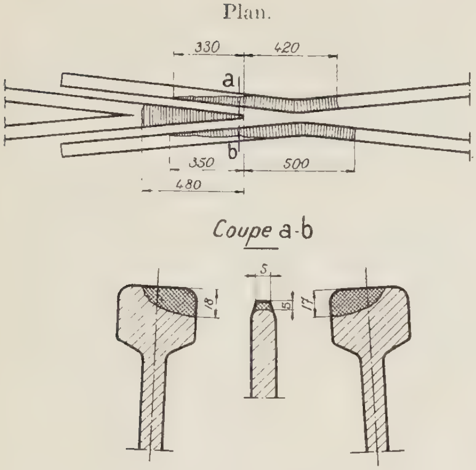

Fig. J. 1. — Building up worn parts of crossing noses and wing rails (*Paris Orléans-Midi* Railways).

up worn surfaces when the general condition of the points and crossings is such that a further 5 to 6 years life can be expected if it is the case of a line carrying heavy traffic. The gauge, level and fastenings must also be gone over and worn bearings and stays renewed.

Some railways, the *Alsace-Lorraine*, for example, when building up worn running surfaces also weld the acute or obtuse crossings to the 12 to 15-mm. (15/32″ to 19/32″) bearing plates carrying them. This lengthens their service life considerably as the distance pieces and fastenings do not become loose as when they are bolted to the bearing plate.

The *Alsace-Lorraine* Railways, as an experiment, have also built up the noses and wing rails of new crossings with extra-hard chrome-nickel steel. The running surfaces were first milled down 1 cm. (13/32″) and then built up with the hard metal in place of the original steel.

These crossings are in use at the Thionville locomotive shed.

The *Czechoslovak State* Railways use cast steel crossing noses bolted to the wing rails, which are repaired when worn as follows (fig. J. 2) :

The worn nose is set up to such a height that the part most worn vertically is to the dimensions as when new. The adjacent surfaces being too high are milled down (parts *c* and *d* of fig. J. 2). The underside of part *f* is then clear of the wing rail foot and the gap is welded

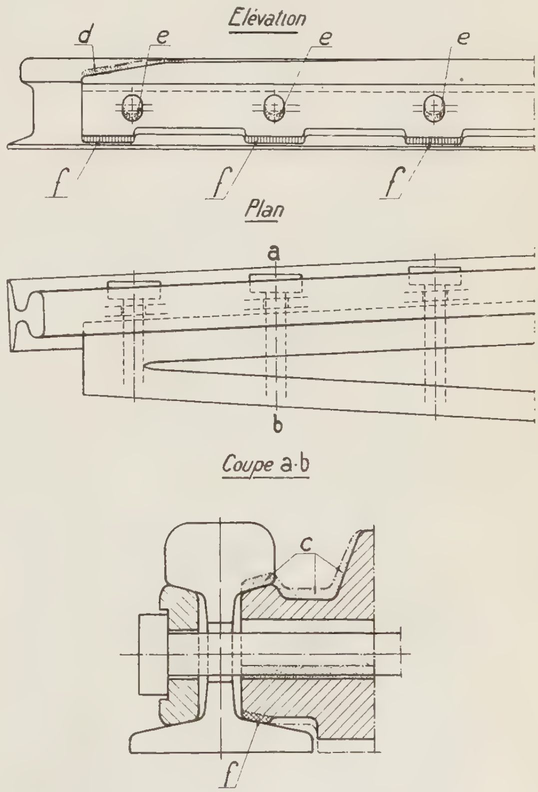

Fig. J. 2. — Repairing cast steel crossing noses (*Czechoslovak State* Railways).

c-d-e Metal removed by milling.
f Parts to be built up with weld metal.

up. Five points and crossings welded up in this way are in service in sidings and a further hundred will shortly be dealt with in the same way.

The *French State* Railways, as an experiment, have built up six cast manganese steel points and crossings which are laid in the slow running roads in the Batignolles and Paris-St. Lazare stations.

2. **Organisation of the building up work.**

Building up as a rule is done in the track, in situ, without taking up or removing the points, at least in sidings.

In the case of points and crossings on heavily used running roads, and also when repairing cast manganese steel crossings, the work should be done off the track. If however any parts, as in some *Czechoslovak State* Railway crossings, have to be machined, the work can only be done in the shops.

Individual points and crossings can be built up in situ. However, the better way as regards time and cost is to draw up a programme for dealing with the different points and crossings in one station or a given area in turn.

3. **Welding processes used for building up.**

Two processes are used : electric arc, and oxy-acetylene.

a) *Electric arc.* — From the information sent in by the *French Nord,* arc welding has the advantage that only a small area of the worn part is brought up to a red heat. The oxy-acetylene process however, heats up and softens the metal to a certain depth, so that during the whole of the building-up work, vehicles cannot be allowed to pass over the crossing. Contrariwise, with the electric arc process, the work can proceed without holding up the traffic.

The current is generally supplied by a portable petrol-engine-driven generating set.

The set and equipment are fitted on a truck which can be moved along the six-foot when building up worn parts of points and crossings in the track without removing them.

Actual building up work. — The metal is laid in longitudinal layers 2 to 3 mm. (5/64″ to 1/8″) thick and 8 to 12 mm. (5/16″ to 15/32″) wide. Each layer has all scale removed before a further layer is added (*French Nord*).

The best results are got from a welding equipment when two welders are employed : The first uses up an electrode and whilst he is clearing the scale away from the added metal, fixes the electrode in the holder and takes a little rest, the second welder lays down a second electrode, and so on. The *French Nord,* for example, uses this method.

Each welder has to use a welding helmet fitted with special glass to absorb the rays dangerous to sight.

Material. — The direct-current generator sets as a rule have a 10 to 15-H.P. engine coupled to a self-regulating generator with the following characteristics when using 4 to 6-mm. (5/32″ to 1/4″) diameter electrodes :

No-load voltage	46 to 60
Average voltage on load.	20 to 25
Welding current regulated by the brushes .	20 to 250 amperes.

If a supply of electricity is available near the job, a motor-driven set can be used or a static transformer giving a voltage of 55 under no load and 20 to 25 under load, the welding current being adjustable between about 30 to 200 amperes.

The current is regulated by a double-pole plug which can be inserted in different connections (a dozen for example).

Weld metal. — The composition of the weld metal has been the object of much research by welding specialists.

It is used in the form of coated electrodes as it has been found the results with bare wire are not so good, the deposited metal being oxidised and brittle. Then too the fused metal, not being guided by the coating as deposited, is irregular.

The coated electrodes on the other hand give a weld of sound non-brittle material of the same hardness as the rail. It also permits the use of elements which increase the hardness, such as nickel-chrome, and manganese, incorporated in the steel.

When building up points and crossings or rails in ordinary steel, the *French State* Railways obtain the best results with electrodes with a semi-volatile coating which protects the molten metal from oxidising, by giving off gases and a liquid slag.

The usual electrode diameter is 4 to 5 mm. (5/32″ to 3/16″) with a 1-mm. (3/64″) thick coating.

The *French State* Railways report that the characteristics of the deposited metal can be :

Tensile strength	55 to 60 kgr./mm^2 (34.9 to 38.1 Engl. t. p. sq. in.);
Elastic limit	45 to 50 kgr./mm^2 (28.6 to 31.75 Engl. t. p. sq. in.);
Elongation on 70 mm. (2 3/4″) .	14 to 17 %

This same Railway, when building up cast manganese steel crossings, uses thick-coated electrodes depositing an austenitic steel containing 13 % of manganese and giving a Brinell hardness of 175 to 200.

b) *Building up with the oxy-acetylene flame.* — This process is relatively little used. Besides softening the metal to some depth, it necessitates a large supply of bottles of compressed gas, which has to be renewed continuously (*French Nord*).

The technique and equipment used is practically the same as with other industrial applications of this welding process.

Some of the railways who have used this process consider it requires greater care and more experienced welders than arc-welding (*French State*).

It also appears to be more costly (*P. O.-Midi*).

The *Czechoslovak State* Railways have used this process in building up four points and crossings. First of all the part to be built up is thoroughtly cleaned to remove all traces of rust and then heated for a length of 10 cm. (4″) near the place the metal is to be added.

Weld metal. — The weld metal is a special low-carbon manganese steel (on the Paris-Lyon-Méditerranée Railways a steel containing chromium as well is used). During the welding this metal becomes carburised by contact with the combustion products of the flame and the carbon content becomes the same as that of the casting to be built up (Data supplied by the *Czechoslovak State* Railways). The metal is deposited in layers of 2 to 3 mm. (5/64″ to 1/8″) at most. The weld is very carefully annealed subsequently.

4. Precautions to be taken when building up details.

If the parts built up are large, precautions must be taken to prevent deformation during cooling.

The *Alsace-Lorraine* Railways in particular, who as we have seen weld the bottom flanges of the rails to the bearing plates of the acute crossings, found this operation tended to make the whole crossing slightly convex.

On the other hand, building up worn running surfaces tends to give the crossing a concave shape and the crossing in certain instances has to be straightened after the welding work is completed.

5. **Completion of the building up work.**

A number of railways (including the *Paris-Lyon-Méditerranée,* the *French State* and the *Czechoslovak State* Railways) vigorously hammer the weld before it cools down, to get rid of any slag in the metal, improve its structure, and reduce internal stresses.

The *French Nord* has found by micrographical examination that with arc welding the built-up rail does not show any alteration in structure likely to give rise to brittle zones.

Building up the surface is usually followed by grinding to clean off all irregularities in the added metal and restore the running surface to the same dimensions as those of new points.

The *French Nord,* however, does not grind the added metal in the case of points used in sidings. All that is done is to level off the surface with a hammer when removing the slag.

The grinding is done by two grinding wheels forming part of the equipment, on a frame with two wheels, handle and slides. The grinding wheel is driven by a 2-H.P. motor running at 2 000 r.p.m., and is brought down onto the rail surface by screws and nuts (figs. J. 2*bis* and J. 2*ter*).

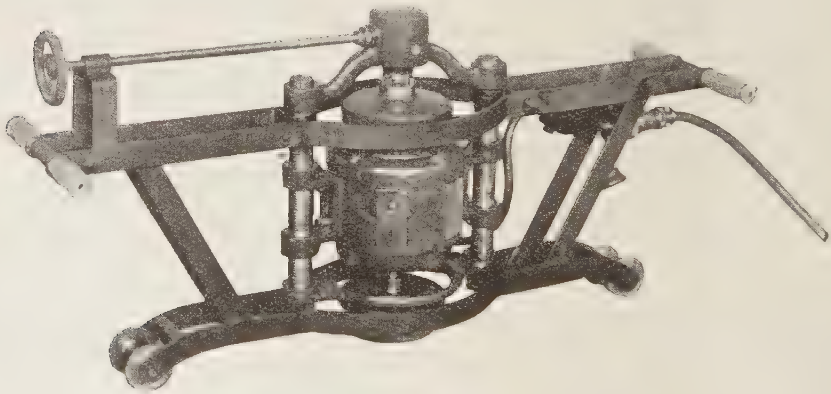

Fig. J. 2*bis.* — Adjustable grinder on mobile frame for grinding built-up surfaces (*French Nord* Railway).

Great care must be taken when grinding, especially at the rail ends in order to remove all irregularities.

Figures J. 3 and J. 4 show an acute and an obtuse crossing built up by arc welding (*French Nord*).

They were taken before grinding so as to show the added metal.

6. **Checking the built-up part.**

The only practical check is the Brinell hardness test. A 200 Brinell hardness corresponding to a tensile strength of 67 kgr./mm² (42.5 Engl. tons p. sq. in.) is generally got (*French State*). It corresponds to that of the rail itself.

Fig. J. 2*ter*. – Use of grinder for finishing rail ends built up by arc welding.

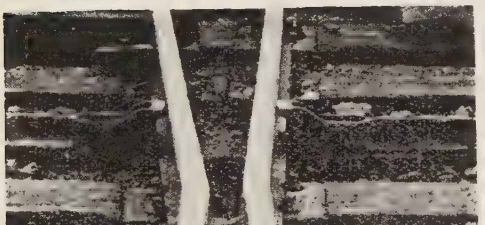

Fig. J. 3. — Acute crossing built up by electric arc welding (*French Nord* Railway).
Photograph before grinding.

Fig. J. 4. — Obtuse crossing built up by electric arc welding (*French Nord* Railway).
Photograph before grinding.

7. Training the staff.

Building up work nearly always is done by railway staff specially trained in welding work, who have had a course of instruction either in the trade or in welding schools. They have to pass an examination.

The supervisors and test-house men are also trained on similar lines.

8. Inspection of built-up points and crossings and results obtained.

Points and crossings built up by welding are examined as a rule periodically, either by the repair staff or by specialist staff. So far no incident or accident attributable to this building up has been reported.

Taken as a whole, the points and crossings built up in this way have given good results.

When the bearings and worn distance pieces and bolts are replaced, points and crossings built up by welding may be said to be as good as new.

Amongst the railways building up by the electric arc, the *P. O.-Midi* and *Paris-Lyon-Méditerranée* Railways report that the weld metal seems to wear less quickly than the rail metal, especially when the details (distance pieces, etc...) of the points and crossings are also welded together. This prevents the joint getting out of order and reduces the shocks from the wheels striking the running surface after passing over the gap (*Alsace-Lorraine*).

The *French State* Railways report that the service life of new and built up points and crossing appears to be much the same.

9. Cost of building up, and saving in maintenance.

The cost of building up an acute crossing by welding varies with the amount of work done (thickness of built-up part, welding or not of details, welding or not the whole crossing onto its bearing plate, etc...).

Taken as a whole the cost of building up a crossing is a quarter of the cost of a new one.

The service life being about the same as that of a new one, there is therefore a definite saving accruing from repairing the points and crossings by welding.

In addition to the saving in renewal cost, there is also the saving in the usual running maintenance. As the running surfaces are restored to their original condition and the parts are welded together, there is less shock when the trains run over the points.

Since building up points and crossings has become general practice, there has been a definite reduction in the consumption of detail parts, which makes it possible to spend more on renewing old light points and crossings by modern designs more suited to present-day traffic.

When building up was introduced, the crossing noses were the only parts to be built up.

Now all possible parts of the points and crossings are welded up and in particular the joints and tongue heels.

The resulting saving is considerable.

II. — Rails in running roads.

Among the railways consulted, the *French Nord* is the only one on which the rail ends are built up to restore the continuity of the running surface.

1. Description of the work carried out.

Such building up differs from that of worn points and crossings, the surfaces of which are not, or little, work-hardened, both because the rails are planed when manufacturing them and are abraded in service so that the added metal can be built into the underlying metal easily. In the case of rail ends, however, a deformed and much work-

hardened part has to be built up. It might be thought that cohesion between the added metal and the underlying metal would be more difficult to obtain. This is not so.

The *French Nord*, who has successfully built up some 2 000 joints in running roads is of the opinion that, when building up rail ends, there are many more chances for the added metal to stand up without flaking or being crushed than would be the case with points and crossings, because the layer of added metal is appreciably thinner on rail ends.

The length and the depth of the surface built up on rail ends vary widely. The length is generally 25 to 30 cm. (10 to 12″) and the depth 1 to 2 mm. (5/128″ to 5/64″), but in certain exceptional cases the length is as much as 50 cm. (20″), and the depth 8 mm. (5/16″).

The question has been raised as to whether the work should be put off until the rails are badly worn at the joints before building up or before they are appreciably out of shape.

The *French Nord* considers it better to build them up before the joints have been badly deformed.

The time taken to build up a joint varies. The *French Nord* estimates that a gang can build up an average of 10 joints a day. The work is always done without removing the rail.

The building up is done by the arc welding process, the technique followed being the same as is used in connection with points and crossings.

It should be noted however that so long as the fishing surfaces have not been made good, a difficult thing to do, the fish-plates cannot play their proper part and the joint will continue to get out of order, more slowly of course than before the ends were built up, as the wheel shocks are less.

2. Results obtained.

Building up the rail ends has given good results on the *French Nord*, though this Company considers such built-up ends have been in service too short a time to state with any accuracy the average service life of a built-up joint.

This Railway thinks that built-up rail ends should make it unnecessary to change individual rails prematurely, solely through the ends being damaged.

3. Cost price and saving in maintenance.

The average cost of building up a joint on the *French Nord* is 25 francs.

No accurate estimate of the savings in maintenance has been made so far, although there is no doubt there is a saving, and one that largely covers the cost of building up by lengthening the life of the rails and reducing the upkeep at the joints.

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CHAPTER K.

Summary and conclusions.

Welding rails.

1. *Welding rails*, first carried out in 1906, has only become current practice since 1927. It is used on all kinds of track, including running roads over which heavy (20 to 22-ton axle loads) and fast (120 km. = 75 miles) an hour trains are run.

For the whole of the railways covered by this report, the number of welds in service amounts to many tens of thousands.

2. The *welding processes* most used are :

a) Thermit-pressure, with a plate of mild steel interposed between the rails;

b) Electric flash-butt welding.

These two processes, the first of which is the older, are used for all kinds of tracks, notably on running roads carrying fast and heavy trains.

A third process, thermit-fusion welding was, until a few years ago, only used in sidings, owing to the presence of cast metal throughout the section of the joint.

Recent improvements of this process will possibly allow of using it also in running roads.

Finally the electric-arc and oxy-acetylene processes have been used, but so far not very extensively.

3. *Breakages and defects of welded rails.*

There have been very few cases of breakage and those that occurred were in welds made when the method was first introduced. They are becoming more and more rare as the processes are improved.

The breakages did not cause any accidents and they did not make any large gap in the running surface and the weld cracked first, so giving time to replace the rail soon enough. The repair of a broken weld causes no more disturbance to the traffic than the breakage of an ordinary rail.

Two types of defects, likewise of no great importance, have been noted :

a) In the case of worn rails with a work-hardened running surface, the welding destroys this work-hardening and the passing wheels form an elongated cup-shaped depression in the zone of the weld. This defect is not very noticeable when running because there is no shock and it can be prevented by suitably heat-treating the joint.

b) Formation of high spots. — This is ascribed to the rails being wrongly set when welding. This defect is avoided by taking a little care in preparing the rails for welding.

4. *Tests of welds.*

The chief tests usually carried out in the laboratories are :

Mechanical tests :

1. Measurement of the surface hardness.

2. Drop tests.

3. Tensile and resilience tests.

4. Static deflection test.

5. Repeated or alternating deflection tests.

Metallographical examinations :

1. Macrographs.

2. Micrographs.

Examination of the magnetised surface with iron filings. X-ray examination.

Mechanical tests :

Brinell hardness tests are made, mainly on the running surface to compare the hardness in the welded zone with that of the body of the rail. If there is a less hardness in the welding zone, there will be a tendency for the passing wheels to form cup-shaped depressions. This test shows the value of hardening the weld zone.

Drop testing already used on most railways when passing new rails in the works, is widely employed in connection with these tests.

The usual method is to allow a 300-kgr. (660 lb.) weight to drop on the middle of 0.70 m. (2′ 3 1/2″) lengths of rail, the rail being carried head down on two supports 0.50 m. (1′ 7 11/16″) apart.

First of all the tup is allowed to fall 0.50 m. (1′ 7 11/16″), then 1 m. (3′ 3 3/8″), then 1.5 m. (4′ 11″), and so on to beakage.

The drop test stresses the rail very differently from service conditions. It

is nevertheless of great value as a method of investigation and comparison. In addition a high resistance to impact is an undoubted proof of good quality and workmanship (freedom from internal defects, and fine grain structure).

The drop tests have demonstrated the great improvement in the quality of the welds when annealed.

In order to measure the impact resistance on lines similar to the resilience test on small notched bars, it has been proposed to break the rail with a single blow from a tup falling a sufficient height. The number of kgrm. (of ft./lb.) absorbed will be a measure of the impact strength.

Dynamometric drop testing machines recording the kinetic energy absorbed should be developed.

Tensile and resilience tests on test pieces cut out of welded joints differ in no way from similar tests on ordinary rails.

Static bend tests carried out under a press are those chiefly used by the works when perfecting a welding process.

Repeated or alternating bend tests subject the rail to stresses similar to those set up in the rail by passing trains. Such tests have been made only occasionally owing to the few testing machines of this type in existence. Besides these machines only subject the test piece to repeated bending, whereas the rail in service undergoes alternating bending. The test is long and its cost high.

Macrographical examinations :

The macrographical examinations reveal with precision the parts of the rail which have been melted during the thermit welding and the position and extent of the casting defects : dendrites, piping, segregation, inclusions, blow-holes, etc...

They also reveal the extent to which rolling fibres in the rails are curved in by the forging pressure.

This kind of examination is a good guide to the technician when endeavouring to improve the welding process, especially in regard to :

— the shape of the mould and the quantity of molten metal to be used in thermit welding;

— the value of the forging pressure.

This test is one to be recommended and is currently used.

Micrographical examinations :

These tests reveal the crystalline structure of the metal and consequently are a guide to the technician endeavouring to improve the steel and reduce the brittleness

In welds made by all processes, the micrographical examination reveals :

1. An over-heated zone with Widmannstätten structure at the centre of the weld : a cause of brittleness;

2. A perlitic area with coarse grain size : brittleness;

3. A self annealed area in which the grain is finer than in the original metal;

4. An area in which the original metal is unchanged.

These examinations show the value of annealing for improving the grain size and reducing the brittleness.

Examination of the magnetised surface with powdered iron.

This process reveals very fine cracks, very difficult to detect in any other way. It is useful in some cases.

X-ray examinations :

This kind of examination reveals any heterogeneity throughout the weld, without damaging the part examined.

It can be used, therefore, not only in the laboratory when investigating improvements in welding practice, but also in the shop and on the job to examine each weld after completion. However, the use of the process so far

has been limited by its high cost and still insufficient sensitivity.

The makers of X-ray plant should endeavour to make the instruments more sensitive (at the present time it is about 1/100th of the penetration) and reduce the price of each radiograph, which in turn depends on the cost of the equipment.

5. *Heat treatment of the welds.*

The different tests made on welds, especially the drop tests, Brinell hardness and the micrographs, show the improvement in the structure of the metal resulting from an appropriate heat treatment.

It is good practice to heat-treat welds, whether thermit or electric, in order to reduce the brittleness and regulate the surface hardness.

This treatment can consist of :

— annealing by heating the metal above the recalescent point and letting it cool slowly, either in the open air or in a casing;

— hardening by heating the metal, as when annealing it, and then cooling it off quickly, say by spraying water onto it.

Hardening the weld in the case of rails already hardened after rolling restores the effect of the hardening in the weld zone and prevents premature wear at it.

6. *Applications of rail welding. Welding worn rails.*

Welding is often used with the object of *re-using rails* taken from the running roads. The ends of such rails are usually worn, whilst the remainder is still usable. About 0.35 to 0.75 m. (1′ 1 3/4″ to 2′ 5 1/2″) of the worn ends is cut off. If the ends of the rest of the rail are bent, they are straightened in a press. If the rail heads show any signs of flaking, the defective part is planed off. The rails are then welded in pairs into 20 to 22-m. (65′ 7 3/8″ to 72′ 2 1/8″) lengths, which can be used again in the running roads.

7. *Composite rails.*

Welding two rails of different section together to obtain composite rails is an excellent method of suppressing the fish-plates connecting rails of different section, a frequent cause of track dislocation. This kind of welding can be done by :

a) Thermit-pressure or electric flash, when there is not much difference between the sections;

b) Thermit-fusion if the difference in weight does not exceed 10 to 12 kgr. (20.1 to 24.2 lb. p. yard);

c) Electric arc or blow lamp in the odd cases of very different sections in weight and shape (for example : grooved rail to a double-headed rail).

8. *Rails of great length.*

a) In tunnels : Many tunnels through which heavy (20 to 22-ton axle loads) and fast (120 km. = 75 miles an hour) trains run, are laid with extra long lengths obtained by welding together rails of the usual length.

The lengths in one piece so obtained vary from 48 to 108 m. (157′ 5 3/4″ to 354′ 4″). Longer lengths (288 m., 981 m., and 1 200 m. = 844′ 10 1/2″, 3 228′ 6″ and 3 937′) have been laid in some tunnels.

Nothing untoward has happened through using such lengths. Their upkeep and the steps to be taken in the few cases of breakage are not of such kind as to hinder their use.

b) In running roads outside tunnels : Except on metal bridges on which some railways have welded the rails into one piece the full length of the bridge, and through some stations where 40-m. (80.6 lb. p. yd.) welded rails have been used, the railways consulted have not used in their running track welded rails much longer than the ordinary rails.

The longest lengths are usually 20 to 27 m. (65′ 7 3/8″ to 88′ 7″). A few 30 to 36-m. (98′ 5 1/8″ to 118′ 1 1/4″) rails have been laid by some railways. Only the *Egyptian State* Railways have laid 1-km. (0.62 mile) rails in a running road.

c) *In sidings* (such as shunting yards, station sidings, lines on which empty stock is worked at slow speeds, etc...) : Some railways have laid much longer rails in such lines than in the running track. The lengths in one piece vary from 30 to 100 m. (98′ 5 1/8″ to 328′) Such rails resist any tendency to transverse deformation thanks to the ballast of the slopes which is very consolidated and compact.

9. *Possibility of using extra-long rails in the running roads outside tunnels and on bridges.*

The use of extra-long rails in such track raises the question of expansion; it is still in the experimental stage.

For ordinary lengths, the railways all consider that the rails should be free to expand or contract between the maximum and minimum temperatures to which they are subjected. The gaps left when laying the rails are such that the rails do not touch at the highest temperature and are not put into tension by the fish-bolts at low temperatures.

With ordinary fished joints with a gap of about 20 mm. (25/32″), the maximum length of the rails can be about 24 m. (78′ 9″).

Some railways, so as to use longer rails, 30 to 60 m. (98′ 5 1/8″ to 196′ 10 1/4″) for example, consider the rails can be allowed to touch at a temperature T_2 below the maximum (60° C. = 140° F. for example) and be in tension at a temperature T_1 above the minimum (— 20° C. = — 4° F.) to which they may be subjected. Under these conditions there is a relatively high compression or tensile stress throughout the whole rail length near the extreme temperatures (60° C. and — 20° C. = 140° F. and — 4° F.).

The compression stress set up at high temperature tends to deform the track, which must have sufficient weight and transverse rigidity to resist such deformation.

10. *The effect of the constraining forces on the expansion of the rails.*

The expansion and contraction of the rails under temperature changes are opposed by the constraining forces of the fastenings and ballast opposing any relative movement between the rails and the sleepers and ballast.

This means that even if the rails are never put into tension nor compression through their ends, the expansion and contraction movements are less than were the rails able to expand and contract freely.

The theoretical study of expansion, taking such constraints into account, leads to the following conclusions :

a) *Law of previous conditions :* The length of a rail depends not only on its temperature but also on those to which it was subjected under previous conditions;

b) The reduction in the amplitude of such changes of length due to the constraints is *negligible* in rails not longer than some *60 m. (196′ 10 1/4″).*

These rails expand almost as though they were completely free, and should the gaps close up at a lower temperature than the maximum they may attain, a compression stress is set up throughout them which increases by SE α for each degree centigrade over that at which they come into contact [SE α = 1 100 kgr. (2 425 lb.) approximately for 46 kgr./m. (92.7 lb. per yd.) rails].

c) In the case of longer rails not exceeding 300 m. (984′ 3″) with a uni-

formly distributed force $p = 300$ kgr./m. (201.5 lb. per ft.) per rail, the constraints reduce the changes in length due to temperature variations considerably. The reduction is the greater the longer the rail. The length L = 300 m. referred to above increases when p diminishes according to the formula :

$$L = \frac{2SE\,\alpha \times 40^\circ}{p} = \frac{89\ 200}{p}$$

in which L is expressed in metres, and p in kgr. per metre of rail.

On the other hand, when the temperature increases, the rail is subject to a compression stress which increases from the rail ends to a maximum in the middle. This maximum, the higher the longer the rail, can reach some forty tons at 60° C. (140° F.) (46 kgr./m. = 92.7 lb. per yd. rails laid at 20° C. = 68° F.).

d) In extra long rails even up to several kilometres, the variation in length under temperature changes are the same as in the 300-m. rails dealt with above.

The compressive stress which at 60° C. is about 40 tons for 46 kgr./m. rails laid at 20° C. extends in the middle part of the rail over a length of

L = 300 m. when $p = 300$ kgr./m.

11. *Joints at the ends of extra-long rails.*

In order to reduce to a minimum transverse deformations of track laid with extra-long rails, it appears advisable that the joints at the ends of such rails be so designed that the latter never come into contact at high temperatures. On the other hand, when the rails are in tension at low temperatures, there is a risk of breakages occurring more easily, and it appears advisable, therefore, that the joints be arranged so as never to put the rails into tension.

Ordinary fished joints seem to be necessary only when the maximum gap between rails reaches a certain limit.

It appears to be good practice to limit this gap to about 20 mm. (25/32″) in order to prevent the shocks due to wheels passing over the joints becoming excessive. For wider gaps, expansion devices similar to those used at the ends of metal bridges should be resorted to.

12. *Inspection tests of welds.*

Owing to the high cost and low sensitivity of X-ray equipment the welds are not subjected to any rejection tests.

The laboratory tests we have described are made for information purposes in order to compare the different welding processes and to be able to appreciate the value of any improvements introduced, or to make sure the weld has been made properly.

13. *Cost price.*

The cost of a welded joint varies considerably according to the process, where made, etc...

Generally speaking the thermit-fusion process is a little cheaper than the pressure process. The electric flash is much cheaper than the thermit processes, provided the cost of the equipment can be spread over a large enough number of welded joints (some 10 000).

It is difficult to put into figures the saving in track maintenance accruing from welding. It is however a real one, owing to the smaller number of fished joints, the maintenance of which (levelling up, small parts, etc...) are estimated by some engineers at 45 % of the total cost of track maintenance. The saving is still greater in tunnels.

14. *Application of welding to the manufacture of points and crossings.*

This application is still not very extensive, firstly because the first trials are of recent date, and secondly because there is a fear that points and crossings would not stand the repeated blows to which are subjected, whereas in a

welded rail the weld does no longer sustain any blow.

Almost the whole of the fabricated points and crossings have been used in sidings. The main applications of welding have been :

— to weld on a bearing plate the different parts, planed from rails, making up the acute or obtuse crossings, and the stock rails;

— to weld the distance pieces to the rails they have to keep to gauge.

The advantages obtained are :

— the details do not come loose, so that the maintenance costs are less (less packing and tightening up the fastenings), and there is less wear in the various parts;

— the repairs may be limited to building up by arc welding the worn running surfaces of the noses and wing rails of the acute and obtuse crossings, and stock rails.

When welded, the design can be simplified. The relatively costly distance pieces in particular, whether cast iron or steel, can be replaced by a length of steel tubing.

Arc welding with coated electrodes is used almost exclusively for this work.

The parts to be assembled by welding must be rigidly held in a jig to prevent deformation due to shrinkage when cooling after welding.

15. *Use of welding in building up worn parts of points and crossings, and rails.*

This application is still but little used, but the saving it gives is such that its use tends to increase.

Crossing noses and wing rails are the parts chiefly built up.

Points and crossings in both sidings and running roads are dealt with in this way. The wear to be made good is as much as 18 mm. (11/16″), though it is preferable to build up as soon as the wear reaches about 8 mm. (5/16″).

Arc welding with coated electrodes is the process most used. A semi-volatile coating protects the molten metal from oxidation by giving off gases and a liquid slag easily removed after solidification.

Some railways have built up crossings in manganese steel.

After building up the worn parts, at least in the running roads, the continuity of the running surface is restored by grinding.

Building up worn points and crossings appears to be profitable. It effects a saving in the cost of renewing the worn parts, in packing the ballast and tightening the fastenings, because the blows from the wheels are reduced.

Building up the rail ends in running roads has only been done so far on one railway, but this seems to be recommendable practice. It should reduce the cost of rail renewals, and of packing the ballast at the joints.

It would be of value to complete it by building up the fishing surfaces.

[625. 2 & 669]

Aluminium Alloy Rolling Stock,

by Ad.-M. HUG,

Consulting Engineer, M. I. Mech. E., Thalwil, Zurich, Switzerland.

SUMMARY. — The author, in 1935, had occasion to collect data on the use of aluminium alloys, and this article describes *the use, either exclusive* or almost exclusive, of such *light metals* in railway rolling stock construction. He gives a concise description with illustrations and a remarkably complete bibliography (1) (in the form of footnotes) of such stock built since 1926, with as many particulars as possible of its behaviour. He also gives the reasons for using these alloys as constructional material.

* * *

The article is divided into 7 chapters :

I. — Main line carriages;

II. — Electric motor coaches;

III. — High-speed diesel articulated sets;

IV. — Light railcars;

V. — Mineral hopper wagons and tank wagons;

VI. — Light-railway and tramway stock;

VII. — Mountain railways.

(1) For general data see the report on Question V : « The use of light metals in rolling stock construction (Railways, tramways and motor omnibuses) » to the XXIVth International Tramway Congress, Berlin 1934 (International Union of Tramways, Light Railways and Public motor omnibuses, Brussels).

Introduction.

The object of this article is not to study the various and widespread uses of light alloys for fittings, such as lining panels, ceilings, roofs, seats, doors, inside fittings, etc., but the *constructional* use of these metals, i.e. their use not only for the above details but for the structure itself including the underframe, and body frame, and in some cases even the bogies, wheel centres, buffers, etc.

In most cases these materials were used to reduce the weight, the reduction being desirable in many cases, and in others necessary and even essential. In some instances they were used to prevent chemical effects, for example to replace iron or steel where the consequences of rusting would be felt. This is the case when certain ores are carried, or in very humid tropical climates where no form of protection has been found sufficient to keep the stock in satisfactory condition.

The object of this study therefore is to give particulars of such stock which has been in normal service some years, and therefrom to draw conclusions on the advantages of such construction in new work.

Aluminium and its alloys differ from iron or steel in their mechanical properties, especially in their low modulus of elasticity (about 1/3rd that of iron), which makes them bend more easily so

that the designer has to take this factor into account.

As this study is solely documentary, it must not deal with the economic point of view, which depends on operating conditions and has to be investigated in each individual case. It may be accepted however that in the work done and described below, the use of light alloys was justifiable in spite of their higher cost over that of other constructional materials.

* * *

CHAPTER I.

Main line carriages.

Drawing-room and sleeping cars of the American Pullman Company (1932-33) [2].

The carriages were manufactured by the Pullman Car & Manufacturing Corporation for the American main-line companies, and were exhibited at the 1933 Transportation Exhibition, known as « A Century of Progress ».

The main point of interest in these vehicles is that they are manufactured almost entirely of aluminium alloys not only the body (underframe and body framing) but also the bogies, equipment, and even part of the electrical equipment. The only details in steel other than some fittings are the wheel sets, springs, coupling gear, headstocks, axle guards, etc.

The first of these vehicles is a sleeping car with an observation car end giving a good panoramic view, and a kitchen. The length of the body is 25.70 m. (84′ 4″) and the total weight 44 metric tons (t.).

The usual American car of this type weighs 82 tons, so that the saving in weight is nearly half. From an European point of view a weight of 44 t. (which almost corresponds to the weight of all-metal modern coaches in use on the European main lines) may seem a rather heavy weight, but it must not be forgotten that according to American standards such carriages have to stand compression forces of some 180 t. and have therefore to be strongly built, especially at the ends. The bogies of this carriage are monoblock aluminium alloy castings (fig. 1); the total weight of each 4-wheeled bogie is 6.1 t., or a reduction in weight of about 46 % relatively to the usual 6-wheeled American bogie required for this class of stock.

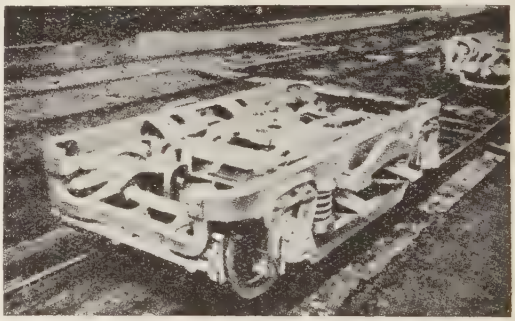


Fig. 1. — Bogie of American Pullman Company's aluminium sleeping car. The frame is a monoblock aluminium casting.

The second vehicle is a drawing-room car (fig. 2) also with an observation room and a kitchen; the body is 24 m. (78′ 9″) long and the weight is 33.5 metric tons. This represents a reduction of 50 % on similar steel coaches. The bogies are built up of heat-treated alu-

(2) See : *Railway Mechanical Engineer*, Philadelphia and New York, June 1933; *L'Allégement dans les Transports*, Lucerne, No. 1-2, 1934.

Fig. 2. — American Pullman Company's all-aluminium (bogie included) observation (drawing-room) car.

minium alloy rolled plates assembled by riveting. The total weight of one of these bogies, also carried on 4 wheels (fig. 2), is about 4.1 t.

The general principles on which these vehicles have been designed were that the construction should be as strong as if made of steel. In addition the modulus of the combined section of the end members at the carriage ends had to meet the specifications of the Pullman Company, which are more stringent than for ordinary stock; in addition the coaches, as we have already said, have to stand an impact force (compression) of 180 t. and a tractive force of 70 t. Finally it was laid down that, taking the structure as a whole, the solebars should be stressed as lightly as possible.

As, owing to the lower modulus of elasticity mentioned above the deflection will be three times as great for equal loads and sections, it will be appreciated that this construction had to meet particular requirements. The coefficient of expansion too is double that of steel. Unlike the usual American practice, *aluminium rivets* were used exclusively.

The reasons which led the Pullman Company to carry out these trials are the following :

With such light stock and the available locomotive power, duplicating trains is unnecessary when there is a rush of traffic which means large operating savings and simpler working.

The use of this much lighter stock also saves fuel, water and lubricants, as well as maintenance costs on the rolling stock, track, permanent equipment and bridges.

Finally the speed up gradients can be raised without double heading.

Double-deck carriage of the Long Island Railroad, U. S. A. (1932) (3).

This coach (No. 200 — see fig. 3) was built to provide the maximum seating capacity with a minimum tare, and for

(3) See : *The Iron Age*, New York, 2nd, August 1934 (1st page of table 1) and figures; *L'Allégement dans les Transports*, Lucerne, Numbers 11-12, 1934, p. 140, and 5-6, 1936, p. 80; *Railway Wonders of the World, London*, No. 38, 1935.

Fig. 3. — Aluminium double-decker suburban coach No. 200.
Long Island Railroad (Pennsylvania).

these reasons was made a double-decker. The Long Island belongs to the Pennsylvania Railroad, and this coach, intended to be marshalled in the electric rakes, was built in the Company's shops.

The body is built of aluminium alloys entirely : main frame, body framing, panelling and interior fittings. The tare weight is 32.5 t. and the number of seats 120. Unlike the European examples, this design is not a real double-decker : the seats are arranged one above the other, access to them being by steps from a central gangway (see fig. 4).

Triple articulated set of the French Nord Railway (1935) [4].

This set for a suburban service is of welded construction, and not riveted as almost universal practice with aluminium alloys.

This method of construction is an extremely interesting innovation and the Rolling Stock Engineers of the Nord should be congratulated for their initiative and pioneering work : they were not discouraged, during the several years the

Fig. 4. — Central corridor of coach illustrated in figure 3, showing the superposed seats.

(4) *L'Allégement dans les Transports*, Lucerne, No. 3-4, 1936, pp. 30-36, and No. 5-6, 1934, pp. 68-69; *Revue Générale des Chemins de fer*, Paris, Nov. 1935, pp. 285-298; *Revue de l'Aluminium*, Paris, No. 64, 1934, pp. 2531-2532. See also *Monthly Bulletin of the International Railway Congress Association*, May 1936, p. 526, and October 1936, p. 1067.

work took, by any lack of success, although the difficulties were very great. Riveting was only used quite exceptionally.

This set consists of 3 bodies carried on 4 bogies. The main frame of each body consists of a welded steel main lattice girder A to which the framing of the welded light alloy body B is fastened (see fig. 5). Rolled sheet has been used exclusi-

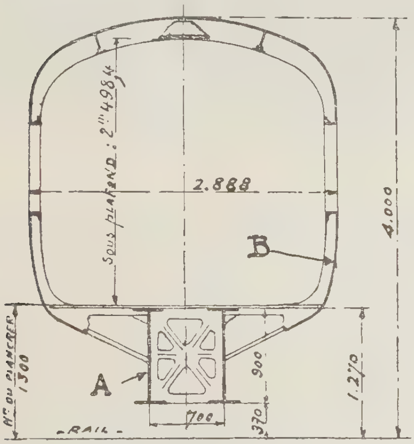


Fig. 5. — Sectional diagram of the framing of the welded light-alloy articulated set of the French NORD Railway.

vely and, as figure 5 shows, the tubular construction principle has been followed so as to get the maximum strength. In addition, through welding being used almost exclusively, the bodies are, as it were, monoblock pieces which adds very considerably to the strength and rigidity of the whole. As high-tensile treated sheets cannot be welded, an alloy had to be selected which would be strong enough for use in rolling stock, and also be weldable. These requirements and many tests carried out by the Nord Railway led to the use of an untreated alloy containing 7 % Mg, known as MG7. In designing the body the welded seams were taken into account and the average tensile strength was taken as 20 to 25 kgr./mm² (28 380 to 35 570 lb./sq. in). The sheets, rolled sections, and other parts are therefore relatively heavy. Nonetheless the articulated rake only weighs empty 75 t., a reduction of 37 % on the weight had steel been used. The length over buffers is 58 m. (190′ 4″) and the number of seats 274.

The weight of the various parts will not be given; full details are to be found in the technical press, and in particular in the publications referred to in footnote (4), p. 268.

The method of welding is also supposed to be known (see type of joint, fig. 6

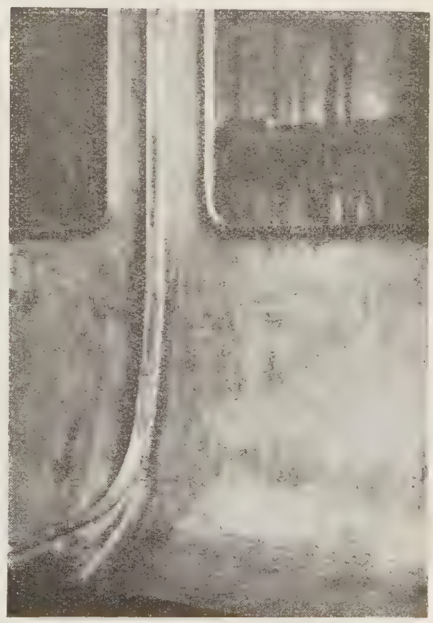


Photo : Ing. Ad.-M. HUG

Fig. 6. — Joint between 2 panels of the French NORD welded light-alloy set.

and publications mentioned in footnote (4). Finally figure 7 shows the central unit being erected.

Fig. 7. — Centre body of the French NORD welded light-alloy set.

This set, like the American Pullman vehicles, is most interesting because it is the result of railway initiative, and was built in the railway shops without assistance from private industry. From the manufacturing point of view it ought to be possible to produce such sets on standardised production lines at reasonable prices.

The set was put into service in the 1935 summer, and was designed to run at speeds up to 120 km. (75 miles) an hour.

* * *

CHAPTER II.

Electric motor coaches.

Pennsylvania Railroad (U. S. A.) electric suburban motor coaches (1926) [5].

Eight of these motor coaches were built by the Company and were put into service in 1926. As at that period experience with light metal was limited, the underframe and bogies were made of steel, the body, including the framing and doors, was built of aluminium alloys. The tare weight of these motor coaches, including the electrical gear, was 50 t. and the number of seats 72, and the weight saved by using aluminium alloys was 10.5 %.

Indiana Railroad System electric motor coaches (Indiana Service Corporation, U. S. A.) (1931) [6].

These motor coaches (fig. 8), 35 in number, were put into service in 1931 and represent one of the most extensive applications of light alloys to railway rolling stock construction.

Fourteen of these vehicles, Nos. 50 to 63, were built in the Jeffersonville (Indiana) shops of the American Car and

(5) See *Revue Universelle des Transports*, Paris, No. 110, 1930, pp. 75-77; *The Iron Age*, New York, 2nd August, 1934 (1st page, 1st table); see also *Railway Age*, New York and *Electrical Railway Journal*, New York, 1927.

(6) See *L'Allégement dans les Transports*, Lucerne, No. 1-2, 1931, p. 24, and 3-4, 1935, p. 46; *Alluminio*, Milan, No. 6, 1934, pp. 337-339; see also the very full report, dated 23rd Nov. 1931, of the « Aluminium Company of America ».

Fig. 8. — Light aluminium electric motor coach, Indiana Railroad System.

Foundry Company, and the other 21 in the Pullman Car & Manufacturing Corporation's shops referred to previously. The vehicles were to be lightened to the maximum possible extent, and yet to be perfectly safe in service. This safety was already demonstrated in the first year's service : two motor coaches ran into one another at 50 km. (31 miles) an hour, i. e. at an absolute speed of 100 km. (62 miles) an hour. In spite of the very violent shock, although the weight of each vehicle is only 24 t., only the end gangways were damaged and partly dri-

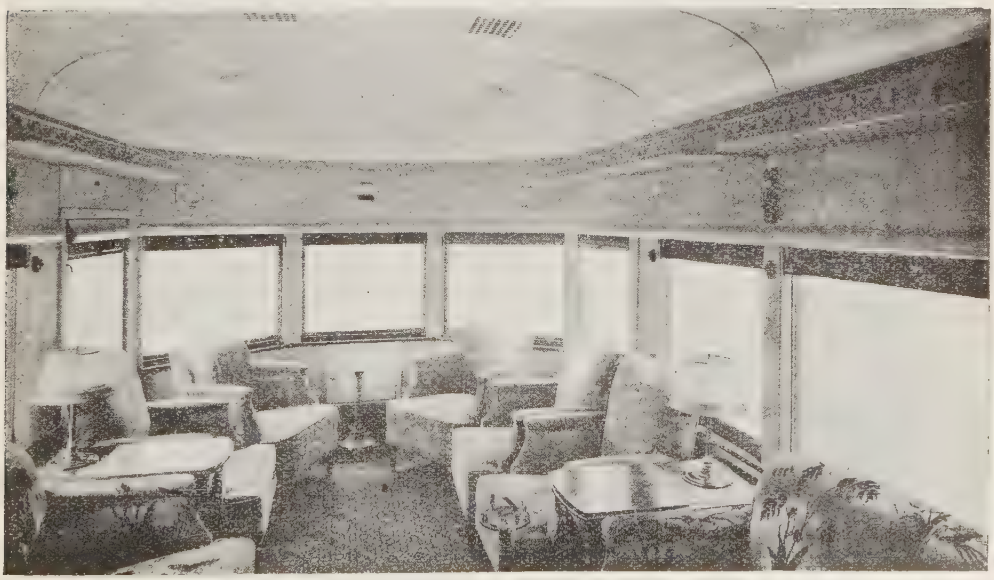


Fig. 9. — Interior of rear section of coach illustrated in figure 8.

ven in. The interior of the body was intact, not a window being broken, nor was any appreciable deformation noticeable. Figure 9 is an inside view of the observation compartment at the trailing end of one of these very comfortable coaches.

The tare weight is 23.7 metric tons made up of : body excluding electrical equipment 9.9 t.; two bogies also without electrical equipment, 7.9 t.; electrical equipment 5.9 t. The average working speed is 60 km. (37.3 miles) an hour, and the maximum allowed in service 115 km. (72 miles) an hour. The body length is 14 m. (46′), and the overall width 2.60 m. (8′ 6″). The overall height above rail

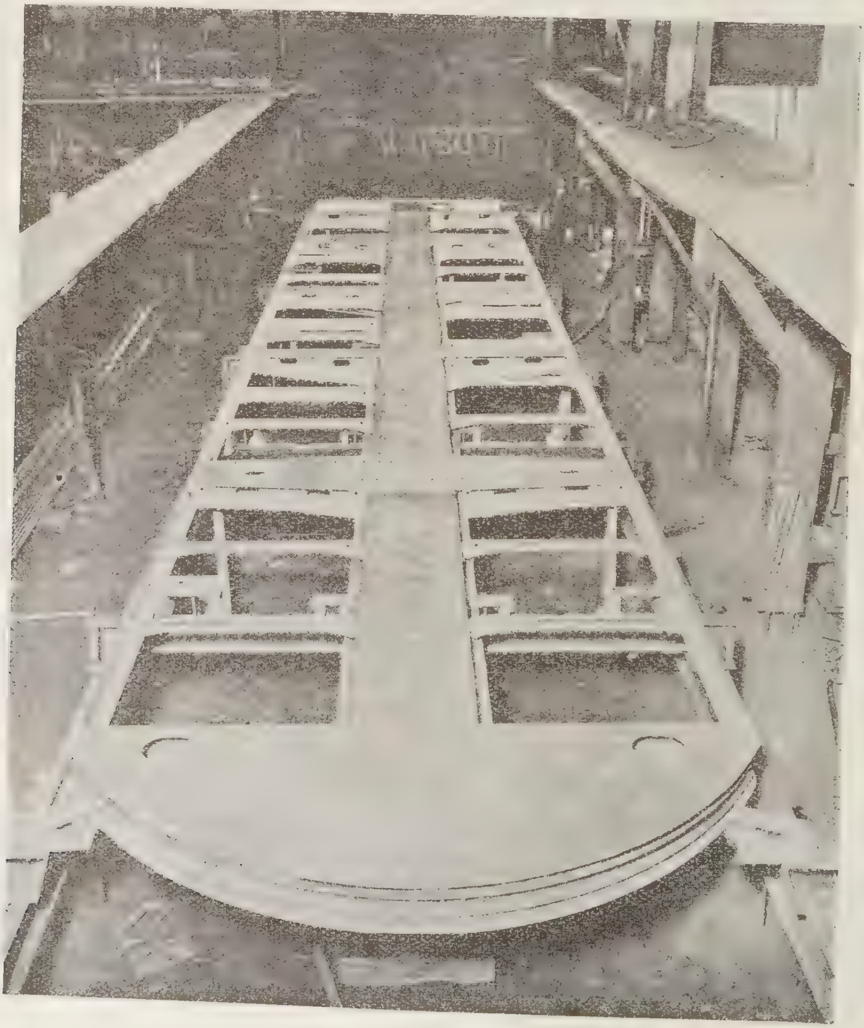


Fig. 10. — Underframe of coach illustrated in figure 8.

is 3.40 m. (11′ 2″). The coaches were slightly streamlined, which was most unusual at that time. The coaches seat 40 and in addition to the saloon and the ordinary compartment, there is a large luggage and mail compartment. The electrical equipment was designed for multiple control, although the coaches usually run as single vehicles.

Figure 10 shows the duralumin underframe during erection, and figure 11 the points where measurements were taken during deflection tests under heavy loads on the first vehicle.

In building the body, the following considerations were taken into account : a main resistance member, a riveted girder, is placed along the longitudinal centre. Parallel thereto on both sides the solebars consist of rolled sections of large dimensions. The central girder is connected to the solebars (riveted connections in all cases) by the massive ends (forming the floors of the end vestibules) and by five intermediate cross members, two of which carry the bogie pivots. Stretchers intended to make the frame still more rigid are provided between each of the cross members. Figure 10 shows this structure very clearly. This very strong underframe carries the body pillars (also of duralumin rolled section) with the waist and cant rails. Above the latter the pillars are connected by sturdy rolled section curved hoop sticks supporting the roof.

The earlier steel coaches, according to the equipment and arrangement, weighed 32 to 46 t. Thanks to the considerable weight saving, it has been possible to make the electrical equipment much less powerful, the capacity of the motors in particular being 20 % less. As regards the economy effected, the railway considers that the additional cost, some 1 500 dollars per coach, due to the use of aluminium, has been rapidly and largely wiped out by the resulting operating savings.

The four suburban motor coach sets of the Berlin Circle and Suburban Railway (Reichsbahn) (1931) [7].

The Deutsche Reichsbahn built and put into service in 1931 on the Berlin suburban lines with third-rail electric traction, 4 trial motor sets, each consisting of a motor coach and trailer (see fig. 12) known as « Quarter trains » (Viertelzüge), the usual train consisting of 4 such sets, all fitted with multiple control. The question was to try using light alloys and see what conclusions could be come to as regards future applications, the intention being to build the bodies and bogie frames of light alloys entirely. For fear of breaking too much new ground, the Reichsbahn altered its plans and decided to use the standard steel bogies. Similarly, some parts of the underframe such as the headstocks, the solebars, and body bolsters were made of steel. The sets were built by the following firms : « Waggonfabrik Wegmann & Co. », Cassel; « Linke-Hofmann-Busch-Werke », Bautzen, and Orenstein & Koppel, Berlin-Spandau. The Wegmann Works, it is interesting to recall, had built at that time a trial bogie entirely of duralumin, of riveted construction. This bogie has since been used for

(7) See : *Glasers Annalen*, Berlin, sect. 1307 of 1931 « Leichtmetall-Stadtbahnwagen » by G. Wagner. See also « Die neuen elektrischen Stadtbahnwagen unter besonderer Berücksichtigung ihrer Massenherstellung », sect. 1250 and 1251 of 1929. See also sect. *Bulletin of the Railway Congress*, May 1932, pp. 582-603.

exhibition purposes. The design was based on the following principles : most of the connections were riveted, the rivets being made of « lautal » alloy having a resistance to shear of 26-28 kgr./mm² (37 000 to 40 000 lb./sq. in.), the diameter being 4 to 8 mm. (5/32" to 5/16") and exceptionally 10 mm. (25/64"). The

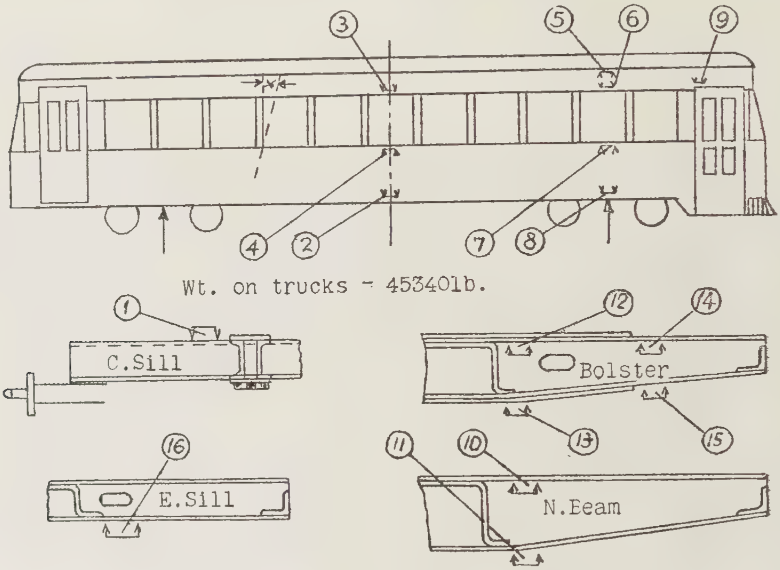


Fig. 11. — Load and deflection tests of aluminium motor coach (fig. 8), Indiana Railroad System.

Fig. 12. — Suburban aluminium train set on Berlin Circle Railway (Reichsbahn).

spacing of the rivets was the closer the smaller the surfaces. The joints were not welded but in certain cases bolts and screws were used, and for the roof covering, S hooks. For comparison purposes, some of the doors were cast and the others built up of sheets rivetted to rolled sections. We will not describe the construction of the body framing, as this has been dealt with already in detail in this Bulletin (see footnote 7). Figure 13 moreover shows quite clearly the method followed.

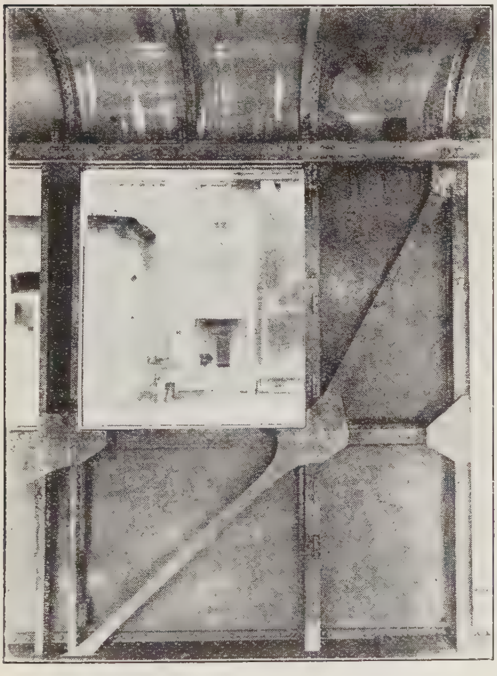


Fig. 13. — Inside view of framing of a motor coach (fig. 12), without the interior lining.

The following are the weights : body without electrical equipment, 26.3 t., i.e. 20 % lighter than the steel coach. The saving on the complete coach was about 10 %. If built entirely of light metal as originally proposed, the weight reduction would have been 48 % on the body, 28 % on the bogies, 18 % on the electrical equipment and the brakes, and finally 37 % on the whole unit in working order. The article we published in the already referred to May 1932 issue of this *Bulletin* also included a calculation of the costs.

Electric motor coaches of the Philadelphia & Western Railway, U. S. A. (1931) (8).

These motor coaches, 10 of which were put into service in 1931, were designed as light streamlined vehicles (fig. 14) for the Philadelphia suburban traffic, especially to Norristown and Strafford. The object of reducing the weight was to give the fastest and densest possible service, the lines in question being in competition with the Pennsylvania main-line and the Schuykill Valley line of the same System, as well as the line of the Reading Company. All three lines had been electrified recently. From the experience obtained with the very light and fast rail motor coaches of the Cincinnati and Lake Erie, it was considered desirable to combine maximum speed with minimum power consumption. With this object the stock was streamlined and lightened as much as possible, whilst making it is small as possible. This led to aluminium alloy construction, the whole body and underframe being entirely of light metal.

These coaches were designed for 3rd-rail traction and multiple-unit control so that they could be run as single, double, triple or quadruple units. These motor coaches, in spite of their low weight are very powerful, as they have four 100-H.P.

(8) See : *L'Allégement dans les Transports*, Lucerne, No. 1-2, 1934, pp. 16-17; also particulars published by « The J. G. Brill Company », Philadelphia, U.S.A. and the « American Car & Foundry Company ».

Fig. 14. — High-speed streamlined light motor coach, Philadelphia & Western, U. S. A.

motors (i.e. 400-H.P. in all), and their maximum speed is 132 km. (83 miles) an hour. So that they should run smoothly at high speed the J. G. Brill Company, of Philadelphia, who built them, endeavoured to keep the centre of gravity as low as posible (less than 1 m. = 3′ 3 3/8″ above rail level). The bogies are the 89 E Brill type with 710-mm. (2′ 4″) diameter wheels and transverse compensating springs. The main dimensions of these most interesting motor coaches are :

Overall length. . . .	17.30 m. (56′ 9″)
Distance between bogie centres	10.40 m. (34′ 1 1/2″)
Maximum width . . .	2.80 m. (9′ 2 1/4″)
Height of roof above rail level.	3.20 m. (10′ 6″)

Weights :

Body, without electrical equipment and brakes	9.85 metr. tons
Electrical equipment and brakes	1.82 metr. tons
Bogies . . . . . 2 × 3.72 =	7.44 metr. tons
Motors with gears	6.28 metr. tons
Total. . .	25.39 metr. tons

The coaches were built to give maximum comfort and were fitted with all the usual safety devices.

Electric motor coaches of the Fonda Johnstown & Gloversville Railways, U. S. A. (1932) (9).

This Railway is a long-distance suburban system which, also owing to competition, had to increase the speed considerably and, in order to keep down operating costs, had to lighten the rolling stock. The old steel motor coaches weighing 39.2 t. were replaced by new ones built of light alloys, and weighing only 19.1 t., i.e. less than half. They are, however, slightly smaller as the trips are much more frequent (see fig. 15). Nonetheless, the power of the motors is the same. These coaches are designed for overhead contact line and for working in single units. Since they were put into service the overall (commercial), speed has been increas-

(9) See : *L'Allégement dans les Transports*, Lucerne, No. 1-2, 1935, p. 10.

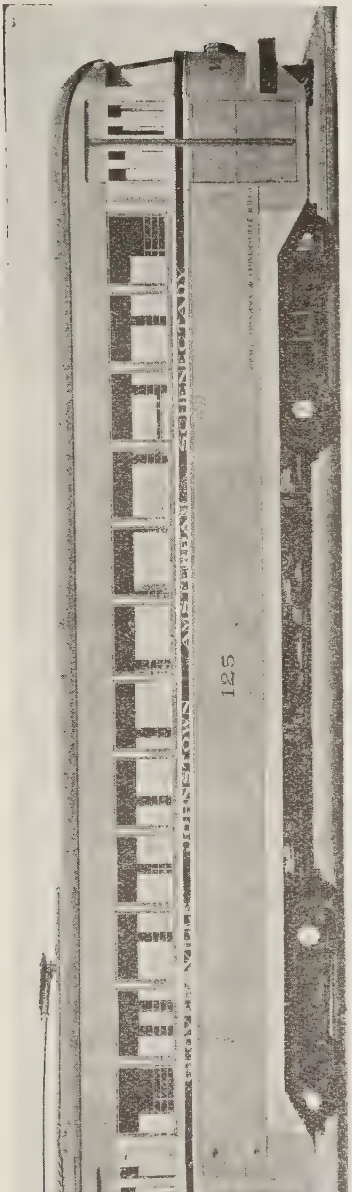


Fig. 15. — Aluminium light motor coach. Fonda Johnstown & Gloversville System.

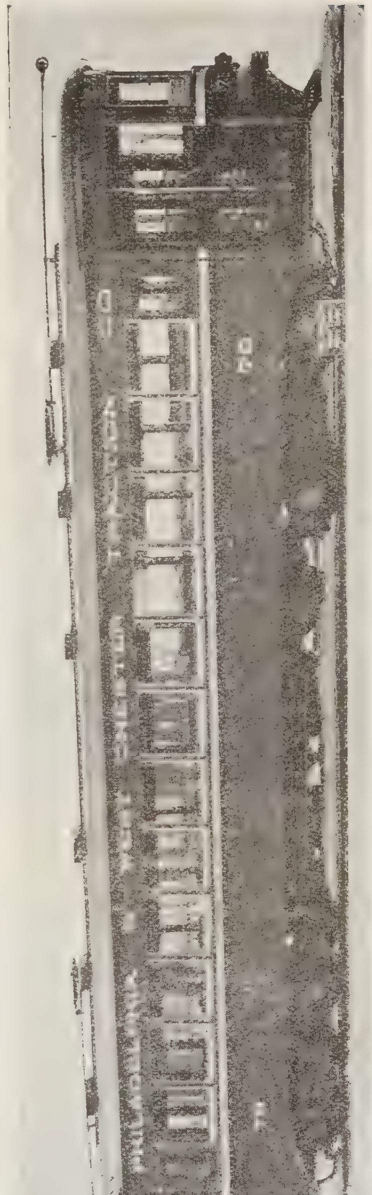


Fig. 16. — Aluminium motor coach, Philadelphia & West Chester Traction Co.

ed 24 %, the maximum speed 12 %, and in spite of the higher speed and greater air resistance the saving in current amounts to 27.5 %. The operating results have shown an effective economy on current of from 1 000 to 1 500 dollars. These coaches too were built by « The J. G. Brill Company ».

Electric motor coaches of the Philadelphia & West Chester Traction Company, U. S. A. (1932) (10).

These coaches, like those of the Fonda Johnstown & Gloversville, are similar in design to those of the Philadelphia & Western. These five motor coaches (see fig. 16) are not streamlined and are slightly heavier, as it was found desirable not to depart too much from the principles governing main-line stock construction.

Also in this case light metals were used in the body only, so that the weight reduction was not considerable.

* * *

CHAPTER III.

Articulated high-speed Diesel-engined sets.

Articulated 3, 6 and 9-car trains of the Union Pacific Railroad Company, U. S. A. (1933-35) (11).

The first of these trains, No. 10 000, of which figure 17 gives a view taken at night, was introduced in 1933. First of all, in view of its interest, we will give a comparison of the weights and capacity of the fast steam steel trains and of the articulated units built to replace them :

	Triple-car motor train of aluminium.		Equivalent steel steam-operated train.	
Length overall	62.3 m.	(204′ 5″)	66.7 m.	(222′)
Width overall	2.28 m.	(9′)	2.48 m.	(9′ 9 3/4″)
Overall height above rail	2.79 m.	(11′)	3.55 m.	(14′)
Average height of centre of gravity above the rail	0.96 m.	(38′)	1.52 m.	(60″)
Tare weight	77 t.	(170 000 lb.)	305 t.	(675 150 lb.)
Number of seats	116		122	
Total weight of the train per seat	665 kgr.	(1 465 lb.)	2 510 kgr.	(5 540 lb.)

These rakes are diesel-electric, and the first three-car set was fitted with a 12-cylinder diesel engine developing 600-H.P. at 1 200 r.p.m. A year later, similar rakes with 6 bodies were put into service and fitted with one 12-cylinder 900-H.P. engine. A year after that, in 1935, two 9-car trains, including 4 sleeping cars, and equipped with 16-cylinder 1 200-H.P. engines, were put into service. All these engines are two-stroke V-type Winton diesels with Westinghouse electrical transmission.

(10) See the J. G. Brill Company's pamphlet; (Philadelphia, Pa. U.S.A.); also the *Electrical Journal* or *Transit Journal*, 1932 (both New York).

(11) See : *Railway Age*, New York, 27th May 1933, 3rd February 1934, 13th October 1934 (3 numbers); also *Bulletin of the International Railway Congress Association*, July 1934. *L'Allégement dans les Transports*, Lucerne, No. 11-12, 1934, pp. 143-147; *Revue de l'Aluminium*, Paris, No. 63, 1934, pp. 2499-2502; *The Iron Age*, New York, 2nd August 1934 : « Aluminium has made rapid strides in railroad rolling stock construction ».

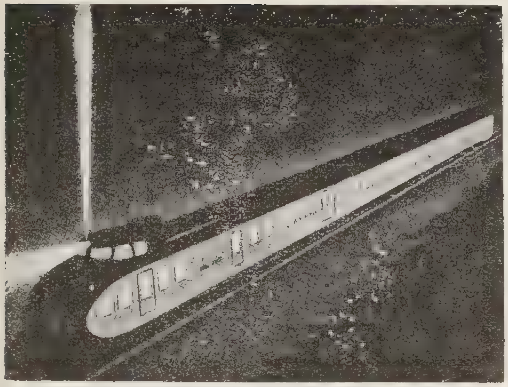


Fig. 17. — Articulated triple-car aluminium train, No. 10 000, Union Pacific Railroad.

These sets were all designed for speeds up to 170 km. (106 miles) an hour, with a maximum speed of 160 km. (100 miles) an hour in normal service. The brakes are designed to give shorter stopping distances than those required for the ordinary expresses running at 90 km. (56 miles) an hour. In view of these high speeds and the need there was for streamlining the stock so as not to require too much power, the articulated design was adopted in order to reduce the space between the body ends and to allow of enclosing this space. In addition so as to make the rakes as light as possible whilst retaining the great strength needed for such service, they have been built throughout of high-tensile aluminium alloy of the duralumin type. The bogies, however, were built of steel with suitable spring gears (see figs. 18 and 19). The bogies of the first rake were also encased for streamlining purposes but this was not done subsequently. On the other hand, the rear end is also perfectly streamlined, the shape of the end being almost spherical. These sets are not reversible in view of the long distances over which they run.

These sets are of tubular design, as illustrated in figure 20, this being the best design for such stock to give the maximum strength. A number of special rolled sections, also shown in figure 20, were manufactured for this stock, so as to get the most scientific design, some of these sections being rather complicated. Figure 21 shows one of these units being erected.

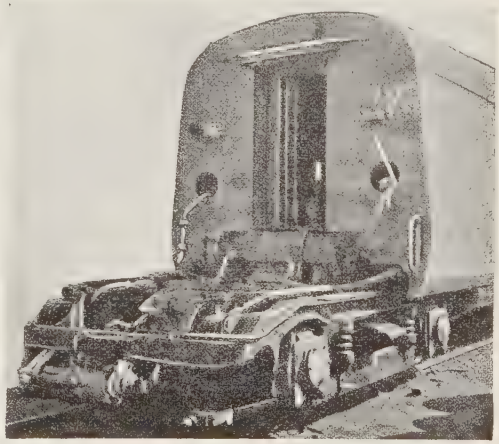


Fig. 18. — Motor bogie and body end of a unit of the set shown in figure 17.

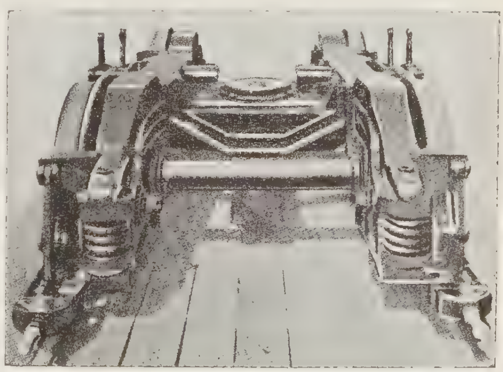


Fig. 19. — Intermediate carrying bogie of the rake shown in figure 17.

The weight is made up as follows : the triple set No. 10 000 weighs in full working order 83 metric tons, i.e. 40 t. for the three bodies when loaded, 19 t. for the 4 bogies, leaving 24 t. for the driving equipment. In the construction of the first train, 29 t. of light metals were used, 15 t. of plate and sheets, 9 t. of pressings or rolled sections and nearly 2 t. of tubes.

A very careful calculation, made before work was started on these sets in the shops and comparing the two methods of construction, shows that a similar train of high-tensile steel, all-welded and as light as possible, would weigh 10 to 20 % more, but would cost a little less. This difference in price was not sufficient, however, to prevent aluminium being used, especially when the operating

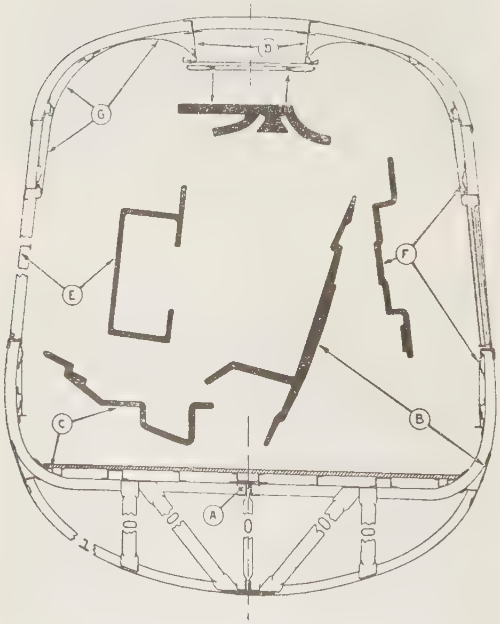


Fig. 20. — Diagram of the tubular construction of the set illustrated in figure 17, showing the special rolled sections.

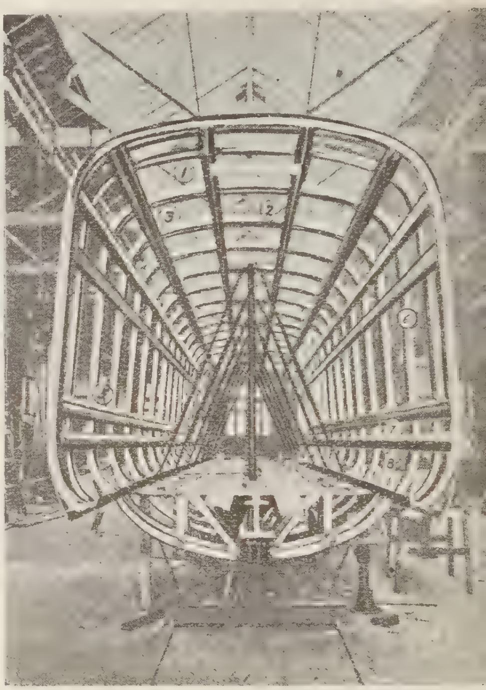


Fig. 21. — Union Pacific set : body under erection.

costs were taken into account. We will not deal with these sets in any detail as many very detailed descriptions have been published already (see footnote 11).

The « Comet » : light-weight high-speed train of the New York, New Haven & Hartford Railroad, U. S. A. (1935) (12).

This train is a triple articulated set (fig. 22), built in 1934 and put into service in the beginning of 1935. It is diesel-electric driven, but can run in either direction so that the two ends are alike.

(12) See *Railway Age*, New York, 27th April 1935; *L'Allégement dans les Transports*, Lucerne, No. 11-12, 1935, pp. 155-157.

Fig. 22. — High-speed diesel-electric aluminium train, the « Comet », New York, New Haven & Hartford Railroad.

The power plant too is duplicated, one set being fitted at each end, and consisting of two 12-cylinder 400-H.P. Westinghouse diesel engines, with generators and traction motors of the tramway-suspended type. The outer bogies are the power bogies.

The set weighs 115 t., corresponding to 720 kgr. (1587 lb.) per seat. This weight is a little greater than the Union Pacific set but the engine power is greater and there are more *seats* (162 instead of 116).

Fig. 23. — Bogie and body end of the « Comet » (fig. 22).

The bodies are all-duralumin and are riveted. The bogies are the cast steel monoblock type with hydraulic dampers (fig. 23). The body is also tubular but the impact strength and rigidity are brought near the main frame as shown in figure 24. The side walls are vertical unlike those of the Union Pacific train in which they are inclined to the inside.

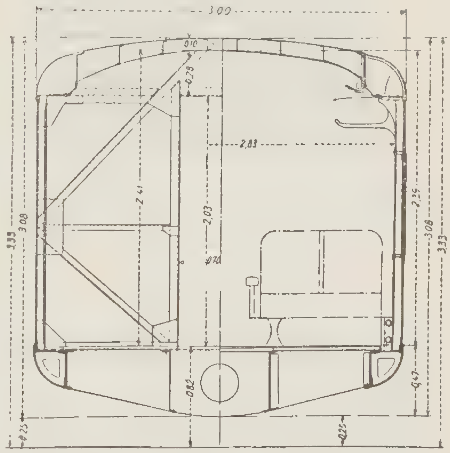


Fig. 24. — Diagram showing the tubular design of the rake illustrated in figure 22.

This train differs from the Union Pacific rake in the body framing, especially in that the ends in front of the engines are of extremely strong, welded steel construction (fig. 25). These ends carry the aluminium body framing.

The brakes are pneumatically operated in three stages to give normal braking and also the most powerful and reliable emergency braking.

The streamlining of these trains is continued down almost to the track and so covers the greater part of the bogies. The maximum designed speed is 175 km.

Fig. 25. — Framing of the front end of the « Comet » during erection.

(109 miles) an hour, but the maximum speed in ordinary service is only 145 km. (90 miles) an hour.

* * *

CHAPTER IV.

Light railcars.

The « Pauline » railcars built by the « Entreprises Industrielles Charentaises » for the French Railways (from 1931) (13).

The first of these railcars (fig. 26) was put into service on the Midi Railway in 1931, and was called « Pauline » after the name of Mr. Paul, the General Manager of the Company. It is driven by a diesel engine through a mechanical gear box, and is especially noteworthy as holding the record for the lightest weight of any railway railcar. The axles and springs are made of steel, but with these exceptions the vehicle is made entirely of duralumin. It has moreover given good service over a number of years, and led to the construction of the improved « Paulines » of which a number are now in use on the French railway systems.

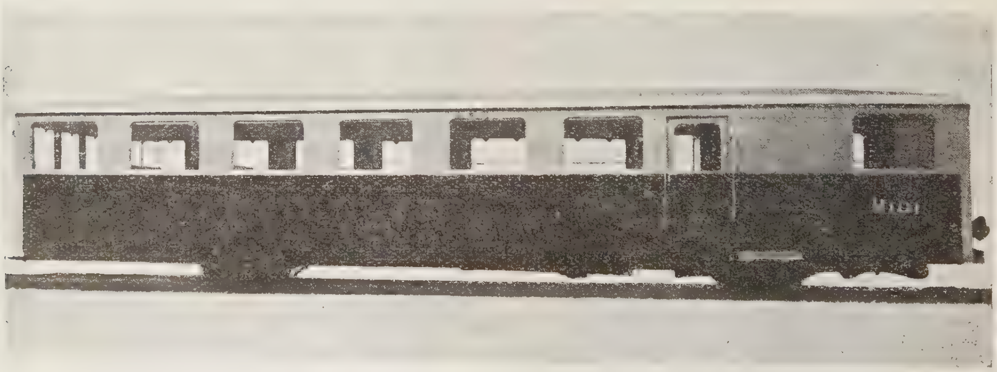


Fig. 26. — Original railcar known as the « Pauline », French MIDI Railway.

(13) See *Revue de l'Aluminium*, Paris, No. 46, 1931, pp. 1565-1572, and No. 66, December 1934, pp. 2642-2643; *Bulletin de l'Association Patronale des Entreprises Suisses de Transports*, Aarau, No. 24, July 1932, pp. 318-319, or *L'Allégement dans les Transports*, Lucerne, No. 9-10, 1932, pp. 83-84.

The overall length of the vehicle is 12 m. (39′ 4″), the wheelbase 6.80 m. (22′ 4″), and the total height above rail level is 2.60 m. (8′ 6″). As it is designed to work as a single unit, it is not fitted with any draw or buffing gear, but only with spring bumpers. The maximum power of the diesel engine is 75-H.P. and the three-speed gear box is designed for speeds of 20, 48 and 95 km. (12.5, 30 and 59 miles) an hour. Light alloys are also used in the engine. The design is such that the stresses in the most heavily loaded cross member never exceed 6 kgr./mm^2 (8600 lb./sq. in.). The stresses in the head stocks are under 1 kgr./mm^2 (1450 lb./sq. in.) in tension and 1.3 kgr./mm^2 (1860 lb./sq. in.) in compression. The main frame is composed of two strong 90 × 180 × 90 × 3 mm. (3 9/16″ × 7 3/32″ × 3 9/16″ × 1/8″) longitudinals built up of U-shaped rolled members weighing 36 kgr. (79.3 lb.), and connected by cross-members. It is on this frame that the body framing of duralumin rolled sections is erected (see fig. 27). The seat frames are curved duralumin sheets only 1 mm. (0.04″) thick.

The tare of this first vehicle was exactly 6.5 t. i.e., 1.4 t. for the wheels and axles and spring gear, 0.78 t. for the engine and gear box, 2.8 t. for the fully fitted body, and the remainder for the other parts. The brake gear is relatively heavy (480 kgr. = 1060 lb.); it was designed to stop the coach from 80 km. (50 miles) an hour in 120 m. (394′) using

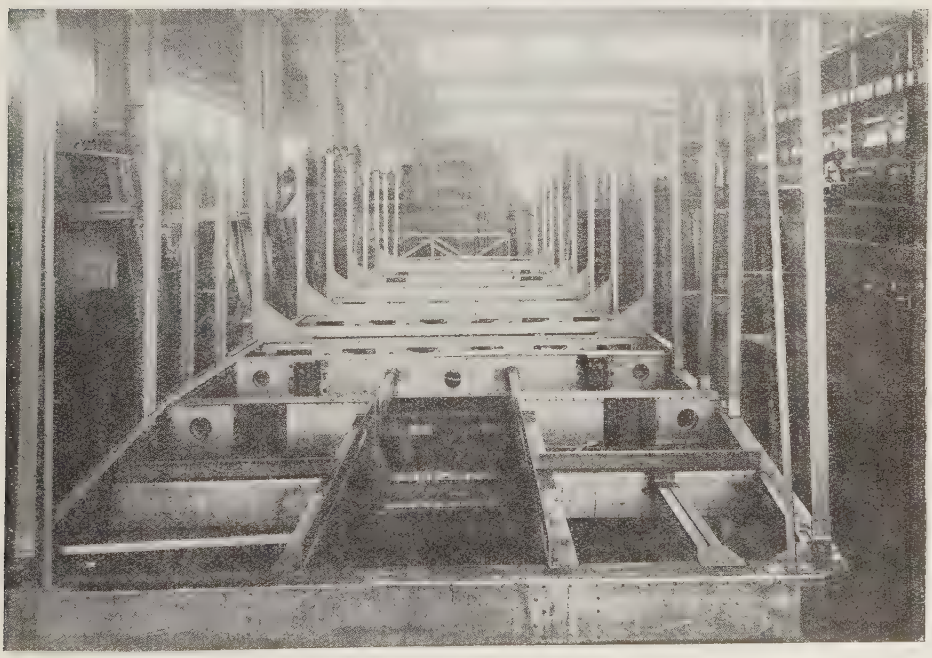


Fig. 27. — Underframe and body framing of the « Pauline » (fig. 26).

sand. As there are 61 seats, the weight per seat is only 107 kgr. (236 lb.) and the useful load is 85 % of the tare, which can be considered a record. The later railcars of this type, more usually called « Charentaises » are carried on 4-wheeled bogies, or 8 wheels, and are fitted with a 120-H.P. engine. The second « Pauline » had a tare weight of 19 t., 5 tons being the weight of the light alloys incorporated in it. The two bogies together weigh 6.5 t. and the engine and transmission 2.2 t. The maximum designed speed is 100 km. (62 miles) an hour.

The more recent types, also of all- aluminium construction are designed more like ordinary railway stock (see fig. 28). The tare is 25 t., the body length 23 m. (75′ 6″) and the engine 140-H.P.. The number of seats is 82 and the speed 120 km. (75 miles) an hour.

These railcars are amongst the most remarkable having been in service on the French Railways.

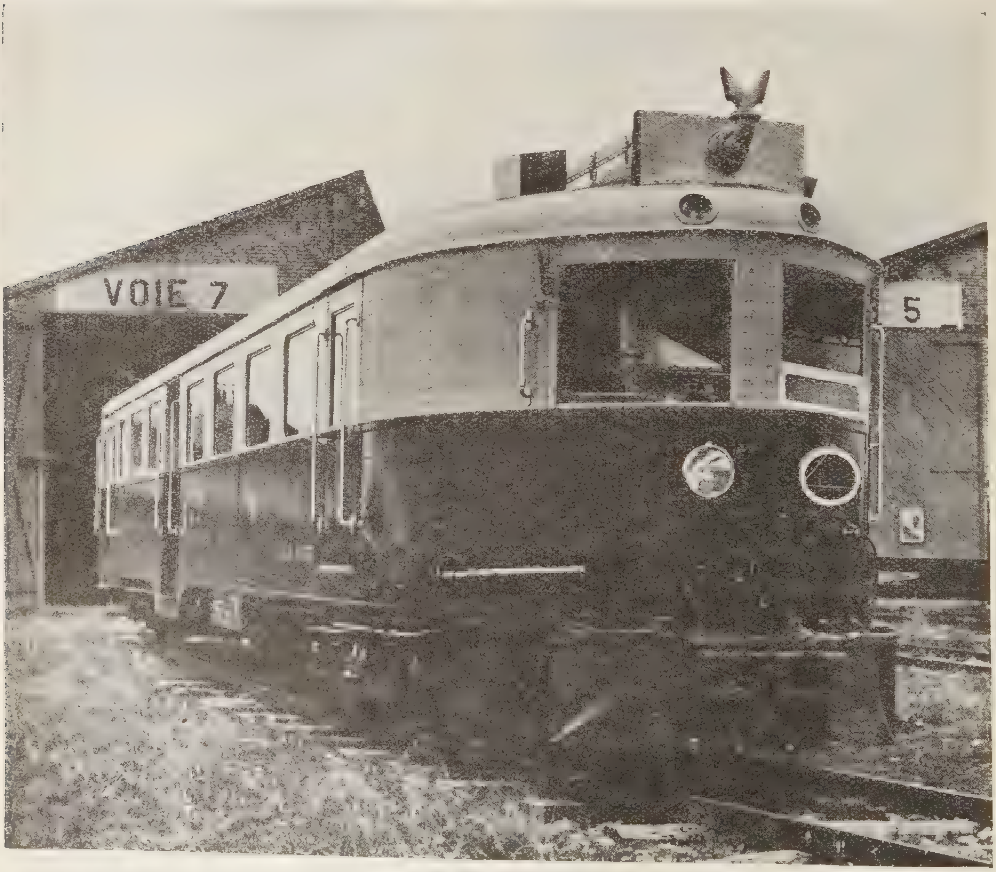


Fig. 28. — « Charentaise » bogie railcar, French EST type.

« Autotram » railcar of the Clark Equipment Company, U. S. A. (1932) (14)

In order to demonstrate the possible operating economies from lighter railcars in certain railway services, the Clark Equipment Company » built the vehicle known as the « Autotram » which went into service at the end of 1932 and, in order to keep the weight as light as possible, was built of light alloys entirely. The main dimensions of this vehicle are : Body length 18 m. (59′ 1″); width overall 2.92 m. (9′ 7″); total height 3.35 m. (11′).

The front end, both the bonnet and the leading section of the driver's compartment, are rounded off and the back end is streamlined. This vehicle, which resembles an omnibus running on rails weighs only 13.6 t. empty and seats 42, i.e. weighs 324 kgr. (740 lb.) per seat. The ordinary service speed is 112 km. (70 miles) an hour and the maximum 140 km. (88 miles). The engine is a 16-cylinder V-type Cadillac of 160-H.P. using 34 to 38 litres of fuel per 100 km. (14.5 to 16 U.S.A. gallons per 100 miles). The bogie and engine are of steel; the body is made entirely of light alloys.

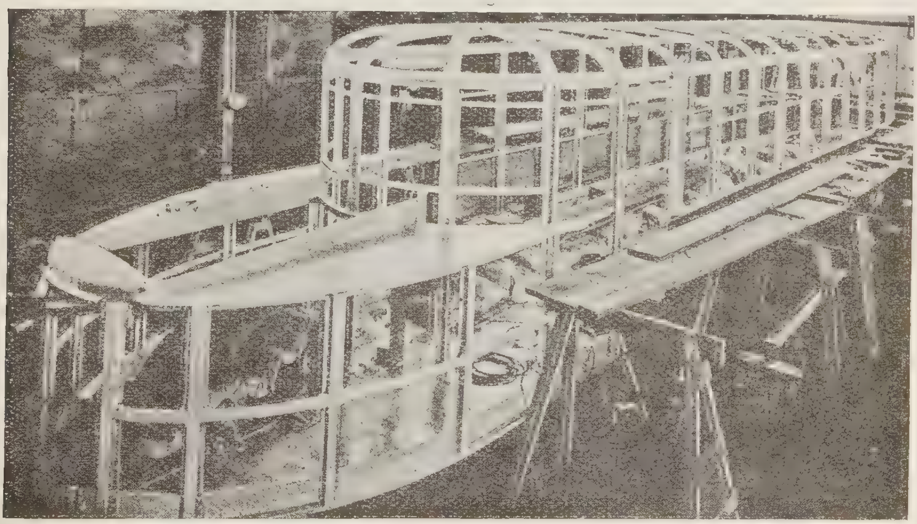


Fig. 29. — Body framing of Clark's « Autotram » (America).

Although aluminium alloys, with their greater cost, have been extensively used, it is claimed that the first cost of such a vehicle is only 5 % of that of an ordinary train and locomotive (*).

The body has the following interesting features, amongst others (see fig. 29) : The main member of the frame is a central longitudinal girder. This girder is fish-bellied and is built of riveted sheets

(14) See : *L'Allégement dans les Transports,* Lucerne, No. 5-6, 1934, p. 69; *Revue de l'Aluminium,* Paris, No. 60, 1934, pp. 2371-74; Publication by « Aluminium Limited », Geneva, 11th May 1933.

(*) Train made up of ordinary stock weighing 500 t. or more, hauled by a locomotive.

and angles. The depth of this main backbone on the centre line midway between the bogies is 622 mm. (2′ 3/8″) and at the ends 165 mm. (6 1/2″). Side shocks from the bogies are absorbed by cast steel plates fastened to the main girder. Rolled channels 101 mm. (4″) wide are used to support the floor and tie the solebars to the central girder. Some of the connecting pieces are light-alloy castings. In order to lessen the air resistance the outside of the body is specially plated. The pillars are duralumin rolled sections, and are connected together by the cornice to which the roof carlines are riveted.

The lights are fixed, the frames being of wood, a special ventilating system being fitted. The waist rail is a 89 × 8 mm. (3 1/2″ × 1/3″) rectangular rolled section, the outside sheeting being 3.2 mm. (1/8″) thick and the roof sheets 2.4 mm. (0.1″) like the inside linings, the whole of duralumin. Several parts of the power equipment, including the refrigerator, the compressor, and the ventilating machinery, are made of light alloy.

* * *

CHAPTER V.

Mineral hopper wagons and tank wagons.

Aluminium hopper wagons of the Alcoa Ore Company, of the Baltimore & Ohio (four 1931) and the Pennsylvania, U. S. A. (1932) [15].

Steel hopper wagons, especially when used to carry coal containing sulphur, or bauxite, are subject to considerable corrosion. This phenonemon takes place so quickly and so seriously that no paint has been found able in practice to resist it.

The Alcoa Ore Company therefore ordered, in 1931, ten 70-t. hopper wagons (see fig. 30) the body and main frame of which are made of treated aluminium alloys alone. Of these 10 wagons, 9 are used daily to carry coal and bauxite, and the tenth mostly to carry sulphur. These 10 wagons have been satisfactory during the 4 to 5 years they have been in service and their maintenance costs have been much lower than those of steel wagons.

The Pennsylvania built, in 1932, a hopper wagon on the same lines, which has also given good results. It is rather smaller, as it carries only 50 tons. In 1934, the Baltimore & Ohio built a number of these wagons (fig. 31).

Besides the much lower maintenance costs, the lower tare weight of these wagons is worth considering, as it would become very important if they were used on a large scale. In the case of the 10 Alcoa Ore Company vehicles, 5.7 t. of aluminium replace 15.6 t. of steel, reducing the weight of the wagon by nearly 10 t. The body of the Pennsylvania wagon only weighs 15.3 t. instead of 21.3 t. for steel construction, which means a weight saving of 6 t. or 28 %.

It is on account of the great danger of corrosion that aluminium alloys had to be used for the body, including the underframe, the cross members, body framing, and coverings, The bogies are of standard steel design.

It is proposed in America to build such wagons on a much larger scale.

(15) See : *The Iron Age*, New York, 2nd August 1934 (same article as « that referred to in footnote (11) ; also *L'Allégement dans les Transports*, Lucerne, No. 1-2, 1934, p. 10; for the « B. & O. » see *Railway Age*, New York, August 1934, and finally the publications of the « Aluminium Company of America ».

Fig. 30. — Hopper wagon, loaded with ore. Alcoa Ore Company, U. S. A.

Fig. 31. — 70 ton bogie aluminium, Baltimore & Ohio Railroad

Tank wagons carrying one or three tanks have been built for the Niacet Chemicals Corporation, Niagara. Such tank wagons were first built as a trial in 1928, and their use has since been extended. At the present time about a hundred aluminium tank wagons are in service for carrying formaldehyde, hydrogen peroxide, acetic acid, and other acids (see *Railway Age*, New York, 22nd February 1936, p. 307).

* * *

CHAPTER VI.

Light railways and tramways.

Instead of describing each individual design, we will only mention here in turn, according to the date they went into service the various vehicles built entirely of aluminium, with reference to the most interesting features.

Between 1926 and 1929, several of the large tramway or light railway systems in the U.S.A. built one or more coaches with a body — and in some instances the bogies — entirely of aluminium in order to save weight and reduce operating costs. These systems are :

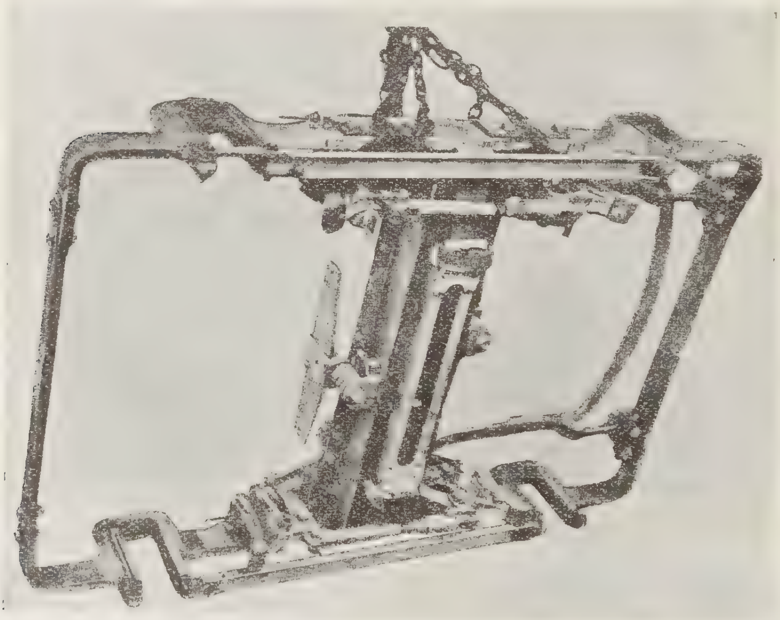


Fig. 32. — Aluminium bogie frame with forged solebars, Cleveland Tramways (Brill construction).

The Cleveland (Ohio) Tramways — one of the first « Peter-Witt » type vehicles (16);

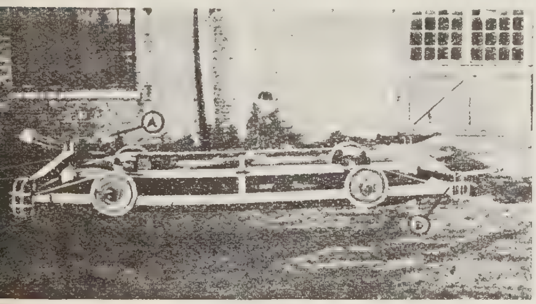
(16) See *Electric Railway Journal*, New York, 4th December 1926 and 19th April 1927; also « Brief Desscription of an Aluminium Car exhibited by the Cleveland Railway Co., Cleveland (Ohio), 8th October 1926 »; *Revue Universelle des Transports*, Paris, No. 110, May-June 1930, pp. 76 to 78, figs. 26 to 29.

The Chicago & Joliet Electric Railway Company, Chicago — designed the well known experimental coach called the « Blackhall Car » after the name of the Vice-President of the Company. This vehicle, which was built by the Cummings Car & Coach Company, of Paris (Illinois), is numbered 200 and named « Louis Joliet » ([17]).

The St. Louis Tramways (1927, see fig. 34) ([18]) — ultra-light experimental car.

The Springfield (Mass.) Tramways — ditto.

The Pittsburgh Tramways — put into service, in 1929, a series of very fast



. — 4-wheeled light-alloy truck of the Blackhall car, Chicago & Joliet Electric Railway.

bogie cars also of the « Peter-Witt » type called « All-Aluminium Cars » ([19]).

All these types of vehicle, part of which were designed for higher speeds than usual on tramways, have some remarkable feature. In the Cleveland vehicle besides the body, the draw and buffing gear, the bogie frames, the motor suspension gear, the brake rigging, etc. are made of light alloys. The bogie solebars are forged duralumin (see fig. 32). The practical results obtained with this motor coach have shown that duralumin rolled sections only 20 % larger in section are practically as strong as steel sections. The saving in weight was about one third, and the saving in power one quarter.

The Blackhall vehicle is quite remarkable in that the weight of the body is less than half that in steel. The tare weight per seat has dropped from 408 to 215 kgr. (850 to 470 lb.). The motors in this coach are fully spring-borne, the drive being through worm gear. Subsequently it has been proposed to build the bogies of aluminium, which will save a further ton on the pair of bogies. The 4-wheeled truck of the first coach was built in duralumin (fig. 33). The brakes act on drums and not on the tyres.

We will also say something about the Pittsburgh « All-Aluminium Cars » whilst dealing with these first American light-alloy tramcars. The most remarkable feature of this car is the bogie (fig. 35) almost entirely of light metal, except for the axles, springs and gears. The boxes (on one of the types) and bogie centres are cast light alloy.

Before going over to the European examples, the motor coach put in service in 1934 by the Chicago Tramways must be mentioned.

In 1933-34 the large suburban tramway system known as the « Chicago Surface Lines Transit System » built two experimental cars on the latest principles with a view to reducing the weight as much as possible ([20]).

(17) See *Electric Traction*, New York, September 1927, p. 453; see also pamphlet published by the « Aluminium Company of America » on the occasion of the A.E.R.A. Convention, at Cleveland, Ohio, 3rd to 7th October 1927.

(18) See *Electric Railway Journal*, New York, 24th December 1927.

(19) See *A.E.R.A. Monthly Magazine*, New York, January 1930.

(20) See *Transit Journal*, New York, June 1934, pp. 174-182; *The Electric Journal*, New York, October 1934, pp. 410-413.

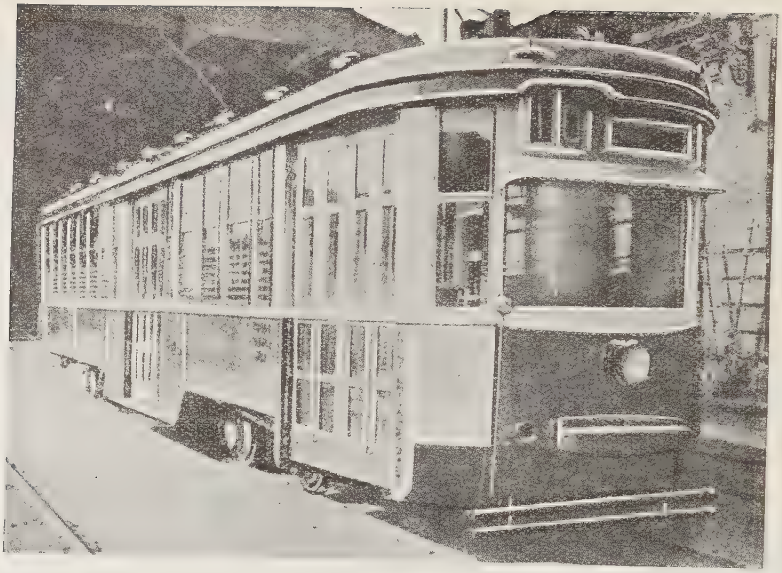


Fig. 34. — One of the fast aluminium motor coaches, St. Louis Tramways.

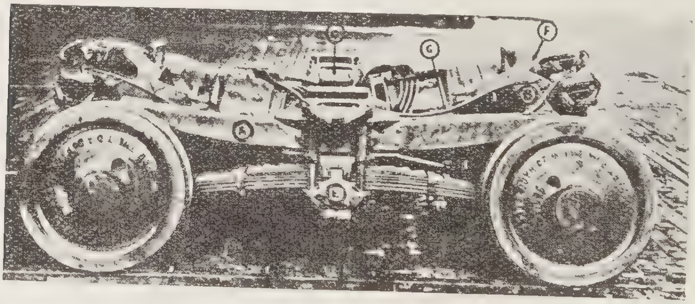


Fig. 35. — Aluminium bogie of vehicle illustrated in figure 34.

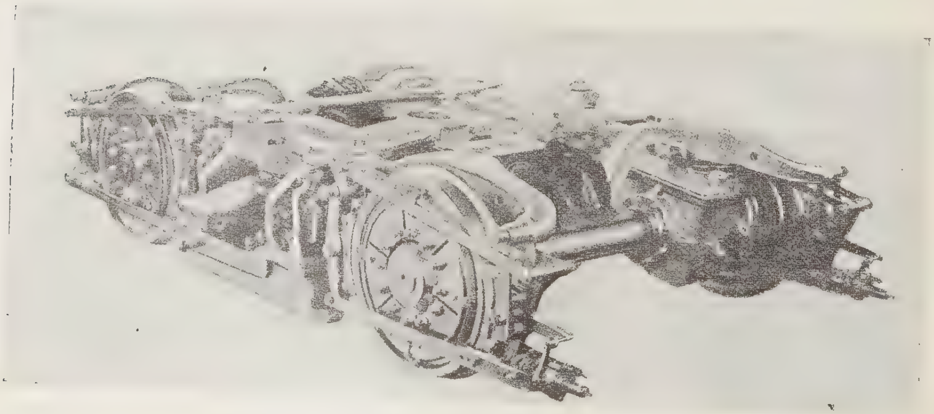


Fig. 36. — Aluminium bogie of motor coach No. 4001, Chicago Tramways.

One of these cars, No. 4001, was built in aluminium alloy by the Pullman Car & Manufacturing Corporation, with Westinghouse electrical equipment. The other car, No. 7001, of steel construction was built by the J. G. Brill Co., Philadelphia, with General Electric electrical equipment.

These cars, of the « Peter-Witt » type, were introduced to meet road competition; they run very well and are noiseless.

The aluminium car only weighs 13.6 tons, a remarkably low weight for 58 seats, besides a large amount of standing room. The bogies are also in aluminium and rubber is largely used in the suspension. The wheel centres are divided into sections with indiarubber inserts (see fig. 36) (*). The 50-H.P. motors are entirely spring borne, the total power being 200 with double reduction gear.

* * *

Let us now go over to European designs, which as regards all or almost all-aluminium construction is limited to 2 trial vehicles on the Naples Tramways (1929) and the Milan Tramways (1936).

These two designs deserve to be described.

Naples vehicle « Azienda Tramviaria della Citta di Napoli » (operated by the « Ente Autonomo Volturno » Electricity Company) (21).

This car, No. 901, was designed in 1928 and built in 1929 by collaboration between the Company and the « Officine Ferroviarie Meridionali » Works.

The body is built entirely of duralumin including the draw and buffing gear. The steel bogies are of the usual design with cast light-alloy wheel centres to reduce the unsprung weight. The use of light alloys has resulted in a 20 % weight saving.

In the spring of 1934, i.e. after 6 years service, the author of this article had an opportunity of examining this car in the Pausilippe depot, at Naples, and was able to see its excellent condition. The use of aluminium alloys has given no mechanical, chemical or other trouble, and has demonstrated the good qualities of this form of construction. The present condition of the car after 8 years service is still very good (see fig. 37).

Milan trial car.

The Milan Tramways « Azienda Tranviaria Municipale di Milano » built in 1935, and recently (1936 summer) put into service a bogie motor coach, No. 5000, with many interesting features. It has been built almost exclusively of aluminium alloys. The axles, tyres, springs, and bogie solebars are steel ; everything else is light alloy : the body including the underframe and body framing entirely (see fig. 38), wheel centres, and axle boxes, equalising levers, bogie bolster, bogie centres, stops and bearings, draw and buffing gear, etc.

The body alone without equipment is 40 % lighter but the more complicated electrical equipment, automatic starting, indirect lighting, and ventilation has meant an increase in weight.

(*) It does not appear possible as yet to express any opinion on this wheel. See : *Proceedings, 1934, of the American Transit Association (Engineering)*, pp. 507 and preceeding.

(21) See *Bulletin de l'Association patronale des Entreprises suisses de Transport*, Aarau, No. 13-14, September 1931; *L'Allégement dans les Transports*, Lucerne, No. 7-8, 1932 and 3-4, 1935; *Annali d'Ingegneria*, Naples, March-April, 1934, pp. 19 to 32.

Fig. 37. - Aluminium motor coach No. 901. Naples Tramways.

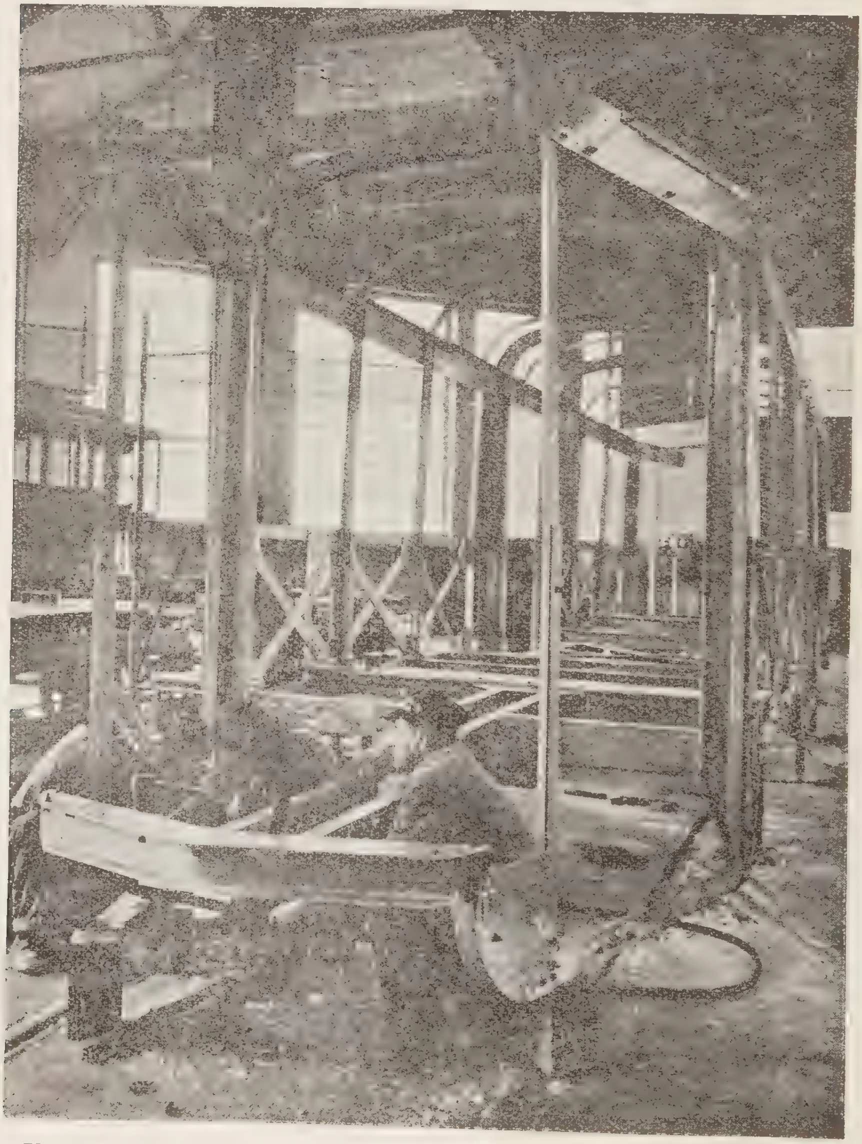


Fig. 38. — Framing of aluminium motor coach No. 5000 during erection, Milan Tramways.

The new motor coach weighs 12.9 t. instead of 15.7 for the standard steel type, or a saving of 18 %. The weight per bogie has fallen from 2.75 to 1.8 t., i.e. a saving of nearly a ton per bogie, or 34.5 %. The unsprung weight too is much lower, thanks to the lighter boxes and wheel centres and bearings; the motor with its double reduction gearing, is also much smaller (22).

* * *

CHAPTER VII.

Mountain railways.

On lines with very heavy gradients, lighter weights reduce the operating costs considerably, and consequently endeavours are being made to reduce the weight to the greatest possible extent.

Aluminium alloys have been used in a number of cases to reduce the dead weight. A typical case is shown by the electric locomotives of the Viège-Zermatt Railway, in Switzerland, for combined rack and adhesion working on a maximum 1 in 8 gradient. The body and body framing of the vehicles are in light alloy which has reduced the tare 5 % and prevented the weight exceeding the maximum laid down. Obviously for this combined rack and adhesion working the motor bogie and frames are very heavy and complicated. These parts will not

Fig. 39. — Aluminium vehicle of the Stoos funicular (Switzerland).

(22) See *L'Allégement dans les Transports*, Lucerne, No. 7-8, 1936, p. 90; *Alluminio*, Milan, No. 3, 1936, pp. 86 to 92, 18 figures and plans.

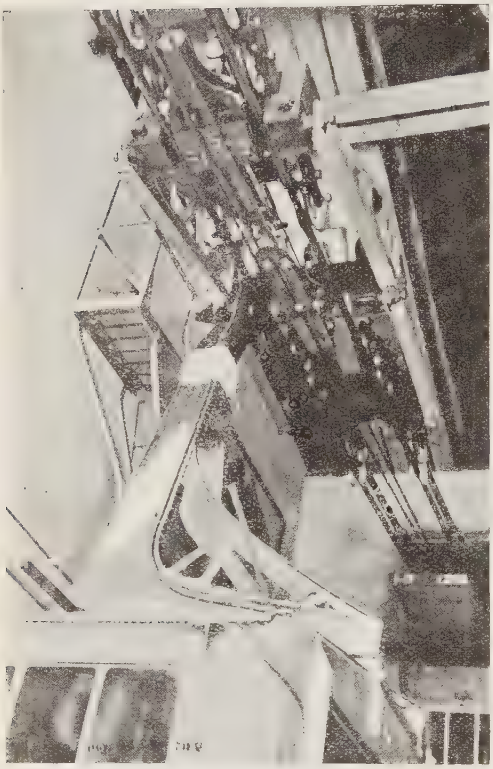


Fig. 40. — Top of the cabin with suspension gear and truck in light alloy on the Trübsel telpher line at Engelberg (Switzerland).

be described here as they have already been dealt with in the *Bulletin* [23].

We will now deal with cable traction lines, and first of all with *funicular* lines on rails for which very light bodies obviously are very valuable. As a typical case we may mention the vehicles of the Stoos funicular, near Schwyz, in Switzerland [24]. Figure 39 shows one of these vehicles.

To complete the article, aerial or telpher lines must be mentioned. Saving weight is of much greater importance in this case than in any other application, as the whole weight is suspended in the air. A number of aerial lines, in particular in Switzerland, Italy and Austria, are equipped with high-capacity ultra-light vehicles wholly built of aluminium alloys. Others are being built in France and Italy.

The applications of light alloys to aerial lines though somewhat differing from ordinary rolling stock, are nonetheless very interesting from the point of view of the results obtained in service. When existing aerial lines are re-equipped with vehicles made of aluminium alloys, of much lower weight and much higher capacity for the same total weight, the carrying capacity of the line (necessarily limited by the load allowed for the cables) can be doubled for an expenditure of some 5 % of the capital cost of the line. Figure 40 shows one of the first equipments of the kind, carried out in 1931 [25].

(23) See May 1932, *Monthly Bulletin of the International Railway Congress Association*, pp. 576 to 578; see also *Bulletin Technique de la Suisse Romande*, Lausanne, No. 26, 1929, and *Elektrische Bahnen*, Berlin, December 1930.

(24) See *L'Allégement dans les Transports*, Lucerne, No. 1-2, 1934, pp. 5 to 9.

(25) See *Schweizer Archiv fur angewandte Wissenschaft und Technik*, Soleure, pamphlet No. 6, « The importance of the carrying capacity of mountain telpher lines » (by the same author with 12 figures); *Revue de l'Aluminium*, Paris, No. 78, 1936, pp. 61-64.

[625. 143.5]

Rails broken in service.

Causes and cures. — Conclusions arrived at,

by J. MERKLEN,
Honorary Chief Engineer Alsace Lorraine Railways,

and E. VALLOT,
Honorary Engineer, French State Railway .

(Le Génie Civil.)

The search for a properly manufactured and non-brittle steel has for a long time been the object of much experimental work, especially since the reports and discussions on this important question, in 1925 and 1930, at the London and Madrid Sessions of the International Railway Congress Association.

These investigations and their results, particulars of which we published in the *Génie Civil* in 1929 and 1934 (1) showed the great difficulty, if not the impossibility, of manufacturing very hard rails with a minimum resilience of 3 kgrm./cm^2 (140 ft.-lb./sq. in.). Such metal would still be far from satisfactory; its resilience would be much below the requirement of 10 kgrm./cm^2 (467 ft.-lb./sq. in.) required for mild steel used in certain metal structures (2), although these never have to stand the violent blows of the wheels on the rails.

Subsequently to our article on the sudden collapse of an electrical transmission line pylon (3) it was found possible to produce rolled sections, large flats and plates in a semi-hard and non-brittle steel. (Tensile : 54 kgr./mm^2 = 34.3 Engl. tons/sq. in. minimum, and 64 kgr./mm^2 = 40.6 Engl. tons/sq. in. maximum; elastic limit 36 kgr./mm^2 = 22.9 Engl. tons/sq. in.; and minimum resilience 8 kgrm./cm^2 = 372.3 ft.-lb./sq. in. in the direction of rolling).

This metal should wear well to judge from the following report made in 1903 on very worn track of the former French Ouest Railway : some mild steel rails had given long service whilst others in hard steel had begun being crushed down.

In our first investigations we pointed out that grooved tramway rails of 81 kgr./mm^2 = 51.4 Engl. tons/sq. in. tensile strength had worn prematurely in the groove and on the running surface. It may seem rational, therefore, not to use the hard rails (Tensile strength = 75 kgr./mm^2 = 47.6 Engl. tons/sq. in.) as now prescribed in the French railway companies' specifications, but to use the lower carbon and non-brittle rails (Tensile strength = 54 to 64 kgr./mm^2 = 34.3 to 40.6 Engl. tons/sq. in.) referred to

(1) Les ruptures accidentelles de rails (Rails broken in service). *(Revue Générale des Chemins de fer,* May 1926). Contribution à l'étude des impuretés dans les rails de chemins de fer (A contribution to the investigations into the impurities in railway rails), *Génie Civil,* 25th May 1926. Ruptures et avaries accidentelles des rails (Rails broken and damaged in service) *Génie Civil*, 5th and 12th May 1934, 22nd December1934 ; also *Bulletin of the Railway Congress*, March 1935, p. 305.

(2) See : Cahier des charges pour l'exécution des construction métalliques des Grands Réseaux de Chemins de fer français. (French main-line Railways specifications for metal structures), July 1904, p. 9; also GRARD and COURNOT : Métaux et alliages (Metals and alloys), vol. 1, pp. 115 and 156.

(3) Remarks on the sudden failure of a pylon *(Génie Civil*, 22nd June, 1935).

above, the resilience of which is 8 kgrm./cm² (372.3 ft.-lb./sq. in.).

Resilience and metallographical tests of each cast would, of course, be substituted for most of the present tests laid down in the specification, the necessity for which we have already pointed out.

In our previous publications, we have brought together, under various sub-headings, the conditions with which the rails have to comply if they are to be laid with confidence, wear well and provide the required comfort by the joints behaving well.

Let us now see if the use of semi-hard rails as defined above meets the requirements thus stated.

A. — *Brittleness.* — *Homogeneity.* — The minimum resilience of a batch of such rails proved to be 8.13 kgrm./cm² (378.3 ft-lb./sq. in.) at the centre of the rail head and in the web, and 11.22 kgr./cm² (523.5 ft.-lb./sq. in.) in the foot, at the top and bottom of the ingot. The maximum value was 15.53 (492.4 ft.-lb./sq. in.) in the middle of the head and from the bottom of the ingot. We estimate in consequence that a minimum of 8 kgr./cm² (373 ft.-lb./sq. in.) can be prescribed in the specification.

As regards homogeneity, the tensile strength varied from 51.5 kgr./mm² (32.7 Engl. tons/sq. in.) at the bottom of an ingot to 58.5 kgr./mm² (40 Engl. tons/sq. in.) at the top of an ingot respectively, and the elastic limit from 29.7 to 36.15 kgr./mm² (18.85 to 22.85 Engl. tons/sq. in). The micrographs showed that the texture was practically homogeneous.

Owing to the inevitable variation of the tensile strength throughout the ingots, its minimum ought to be fixed at 58 kgr. (36.82 Engl. tons/sq. in.), with a minimum elastic value of 36 kgr. (22.85 Engl. tons/sq. in.), figures got from the top of the ingot investigated. Recent records show that these requirements (very near the tensile strength $\doteq$ 60 kgr./mm² = 38.1 Engl. tons/sq. in., minimum of the German State Railways) can be inserted in the specifications and be easily observed.

B. *Segregation.* — Inverted segregation, revealed by some macrographs, has been ascribed to rolling before the ingot had completely solidified, such rolling being known as « laminage trop jeune » (premature rolling). It was also thought to occur in ingots turned on their side before complete solidification.

More probably, as we noted in our first investigations, it is due to a more or less marked liquation of the carbon, produced during solidification. This liquation produces hypercarburized zones, with possibly dangerous carbon contents in hard steels (0.41 to 0.50 C.); it is however harmless with a semi-hard 0.22 C. steel.

If, as recently recorded in the United States [4], internal fissures (« Silvery oval spot ») result from tears produced during the manufacture of rails, a very resilient steel such as a 0.22 C. will be less subject to such tearing and the number of rails affected by such defects will be much reduced.

C. *Piping.* — As we wrote under this same sub-heading, the extent of piping is in direct relation to the deoxidation of the steel. When the steel has been fully killed, the length of the pipe extends to 58 % of the height of the ingot without riser, poured in a straight ingot mould; consequently if the piping is to be eliminated completely, the discard from the top of the ingot must be the same amount.

If, however, it is known the steel is not brittle, a small split in the web can be tolerated as being unlikely to cause the rail to break.

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(4) See *Bulletin No. 376 of the American Railway Engineering Association.*

D. *Wear.* — As has been shown above, semi-hard rails will resist wear well enough. In our first article (*Génie Civil,* 5th May 1934, p. 403) we pointed out that the wear and crushing of the running surface was not caused by the tonnage carried nor by the rail being too soft, but was due as a rule to the metal not being sufficiently deoxidised, which is also harmful because of the splits in the rail foot and star cracks in the bolt holes it can cause.

Insufficient deoxidation is shown by the micrographs as is any lack of homogeneity.

E. *Heat treatment of the rails.* — Heat treatment of the rail head is admitted to be essential with hard steel; contrariwise, if the steel were semi-hard, the superficial surface cracks would be rarer and if they occurred, they would not end in breakage, owing to the steel not being brittle. It is nonetheless desirable to heat-treat the steels of all grades as it artificially work-hardens the running surface and increases the resistance to wear.

It should be remembered, as we have already pointed out, that this treatment would be the more effective the softer and better manufactured the steel (5).

Furthermore, as the steel is not brittle, when inspecting rails in the works, those with slight surface defects (lines, reeds, folds) could be accepted though justly rejected if there is any fear of the rails being brittle. This would mean fewer rejections and consequently a lower cost price.

In addition semi-hard steel would be less destructive of the locomotive and wagon tyres, which would also mean an economy of some importance.

Should it be suggested that the semi-hard rails would wear more at the joints, the reply is to be found in a note recorded when the former Compagnie de l'Ouest took over the Eure System. During a tour of inspection on a main line locomotive over this system which was laid with 30-kgr. (60.5 lb. per yd.) rails of ordinary quality, no shock was experienced at the joints supported in the old way. At the same time an examination of the lines showed they were very well maintained by a district engineer who watched the work done by his men very closely. The kind of joint and not the quality of the rail steel should therefore be questioned and, for this reason, we have recommended the supported joint combined with heat treatment of the rail ends as suggested by Mr. SERVAIS. Other joints, such as the boltless for example (6), deserve to be improved upon and used generally; in any case they have the good feature of eliminating the bolt holes which, apart from star cracking, weaken the rail over an appreciable extent of its section.

Moreover rail welding appears to be becoming general practice. An article in the *Railway Gazette* of the 6th March, 1935 (7), calls attention to a large-scale application on the Delaware & Hudson Railroad, ignoring expansion, which is hindered by fastening the rail foot down very tightly on to metal bearing plates by means of spring clips which, it seems, prevent the rail expanding or creeping (8). Several miles of track were

(5) See : *Ruptures et avaries accidentelles des rails* (Rails broken and damaged in service), sub heading E : *Traitement thermique des rails* (Heat treatment of rails).

(6) See report by Messrs. CAMBOURNAC and PATTE, Madrid Congress, 1930 : Levaire joint, p. 1002, II-80, fig. 41, October 1929 *Bulletin of the Railway Congress).*

(7) See also *Bulletin of the Railway Congress*, August 1936, p. 848.

(8) It appears that the steel spring wedges used with bull-headed rails and cast iron chairs can also be so tightened up and more easily. This type of track was formerly used in the West of France and still is in England, and is more rigid than the Vignole track. The rails are more homogeneous. The head would wear well after being treated by the Neuves-Maisons process which is now generally used under various forms.

welded up in this way without difficulty in 1934 and 1935.

It is as well to add that semi-hard rails would be easier to weld and *would be safer* than higher-carbon steel rails. Welding is more difficult the higher the carbon content, which also favours the structure typical of over-heating, which is characteristic of brittleness.

CONCLUSION.

The strength of the track requires that :

1. rails of a steel capable of standing the dynamic stresses set up by the trains be used;

2. As nearly perfect as possible fastenings of these rails to the sleepers be evolved.

We think the choice of a steel of the quality we are recommending justifies the sub-title of the present note by *finally disposing of a question which has been investigated a very long time* and has to be solved without further delay in view of the constant increase in train speeds.

Secondly, the moment is ripe for improving the method of fastening down the rails, either by using steel bearing plates and suitable clips, or by using bull-headed rails with cast iron chairs and spring wedges.

Even if the wear of the semi-hard rails proved nevertheless to be greater than that of the hard rails now used, it would be preferable to bear such extra cost instead of giving up the precious advantages, from a safety point of view, of eliminating rail breakages or at least considerably reducing their number.

Finally, higher resiliences being obtainable with semi-hard steel, its use can be considered for tyres, the fractures of which led the French Companies a number of years ago to prescribe metallographical and resilience tests (9).

Homogeneous and non-brittle rails and tyres *so intimately connected in their use* (10) would make true Ch. Fremont's recipe for complete safety : « prevent the supply of heterogeneous metals and above all of brittle steels ».

(9) See : Measures taken by the French Railways to improve the quality of the tyres, by M. ARTIGNAN, *Revue Générale des Chemins de fer*, March 1936, and *Bulletin of the Railway Congress*, September 1936.

(10) See « Rail and Wheel », by W.C. Cushing, *Bulletins* 315 and 324, 1929 and 1930, *of the American Railway Engineering Association.*

[625. 234 (.91)]

New air-conditioned coaches for Malaya.

(*The Railway Gazette.*)

The first air-conditioned coaches in the British Empire were placed in service on the Victorian Railways about a year ago and were described in *The Railway Gazette* of April 3, 1936. So popular have they proved that air-conditioning equipment is to be installed on many more passenger vehicles in Victoria, and we predict that it will not be long before air-conditioning becomes as common in certain countries where climatic conditions are extreme as it is already in the United States. An ingenious demonstration staged at Birmingham and attended by numerous railway and other visitors from all over the country has brought home the benefits of this system of railway carriage ventilation. A new coach (described hereafter) for the Federated Malay States Railways equipped with air-conditioning plant was enclosed in an insulated compartment in the works of the builders; the air-conditioning plant was set to work, and the visitors, having experienced the almost tropical heat artificially generated in the compartment, were admitted to the interior of the vehicle. Whereas outside the temperature had been over 90° F. and the humidity 68 per cent, inside the temperature was only 72° F. and the humidity 58 per cent. In other words those who had taken part in the demonstration passed from an unpleasantly hot and moist atmosphere to one that was thoroughly congenial. We can well imagine that, with the placing in service of these coaches in Malaya, travelling, instead of being an experience to avoid, will become such a pleasure that many will find excuses for a railway journey simply to enjoy the atmosphere. Although the cost of air conditioning equipment is appreciable, it has been estimated that all additional charges in respect of it are covered by one extra passenger on an average trip. As the windows and doors of an air-conditioned coach are kept closed, draughts, dust and soot are absent, while noise is minimised.

(Editorial, *The Railway Gazette.*)

* * *

Two first-class carriages of special design and fitted with Stone's electro-mechanical air-conditioning equipment, have been built by the Birmingham Railway Carriage & Wagon Co. Ltd., for the metre-gauge Federated Malay States Railways, to the specification and requirements of the Chief Mechanical Engineer, Mr. A. W. S. Graeme, and to the order and under the supervision and inspection of the Crown Agents for the Colonies. The following are the leading dimensions :

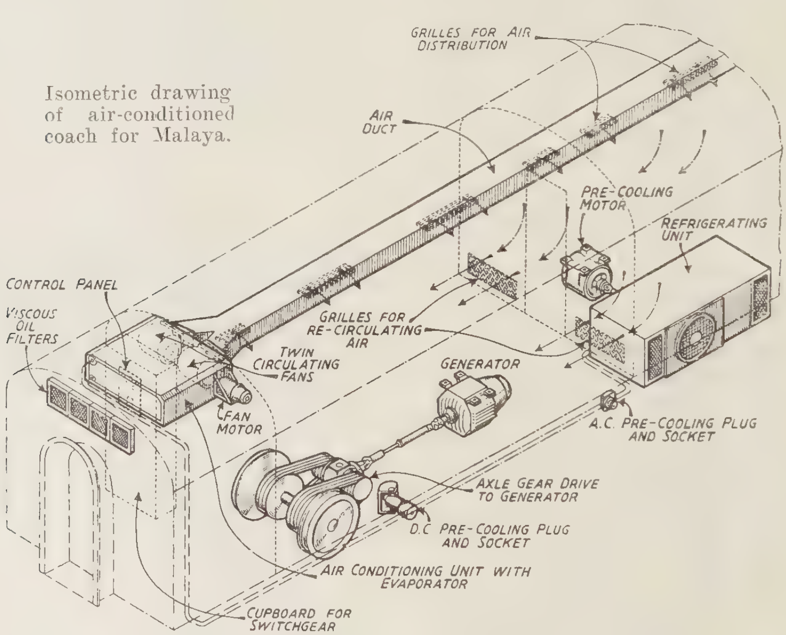
Length over body. . . .	60 ft. 0 3/8 in.
Length over vestibules. .	62 ft. 6 in.
Width of body at waist.	8 ft. 10 11/16 in.
Height from rail to top of roof	11 ft. 8 in.
Centres of bogies. . . .	42 ft. 0 in.
Bogie wheel base. . . .	6 ft. 6 3/4 in.
Diameter of wheels . . .	2 ft. 9 1/2 in.
Buffer height from rail, light vehicle	1 ft. 10 3/4 in.

The specially insulated body and the underframe, built integrally, are of all-steel construction. The floor consists of a double layer of tongued and grooved teak boards with an insertion of cork

insulation between. The walls of the body are double with an air space between them, and cork is the insulating material used generally. Bon-ply birch sheets are used for the interior panelling from floor to cantrail, and the ceilings are of Sundeala. The interior decoration is of Rexine, and this, together with the final painting and varnishing, will be applied after the vehicles reach Malaya, where the chairs, tables and other interior furnishing will be fitted. There are two large open saloons with accommodation for twelve and eight passengers respectively, a small four-passenger compartment, and lavatory. Entrance to the coach is by means of end vestibules.

Double lights are provided at each window opening. They are normally fixed, but the inner lights, fitted with budget locks, are so arranged that they can be easily removed to clean the glass.

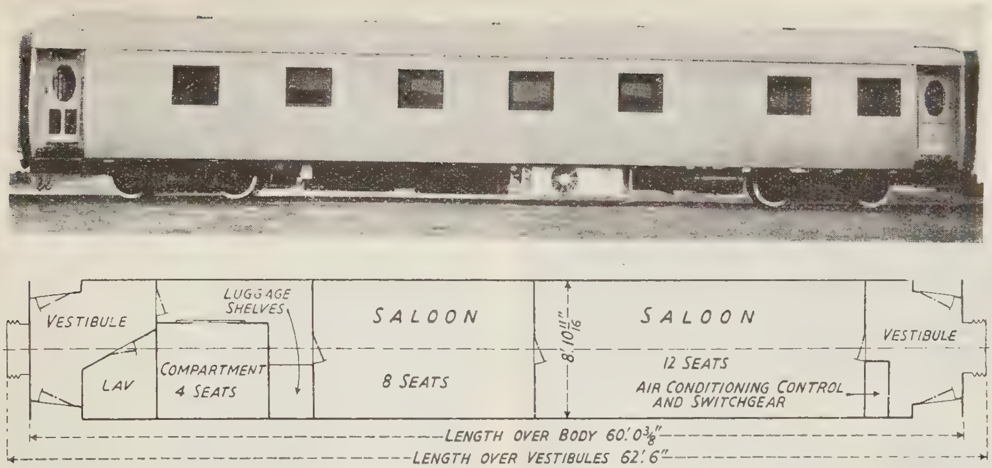
Isometric drawing of air-conditioned coach for Malaya.



In addition, several of the exterior windows are arranged so that they can be hinged inwards for ventilation if occasion demands. Roller blinds in Pantasote are provided at each window. All the electric lighting fittings have been supplied by J. Stone & Co. Ltd., and are of the new Luxton type with opal non-glare glassware. The current for these is taken from the generator and battery, which forms part of the air-conditioning plant.

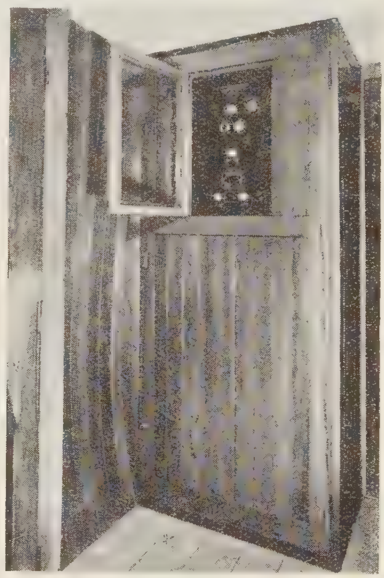
Automatic vacuum brake with two Prestall cylinders is fitted, and there are passenger alarm signal discs of the railway company's standard in the saloons. The bogies, which have Hyatt roller bearing axleboxes, are of the equalising beam type with quadruple elliptical bolster springs and triple coil side springs.

The air-conditioning equipment is designed to provide an ample supply of fresh air, free from dust, for the 24 passengers, and to maintain automatically the correct temperature and degree of humidity inside the compartments so as

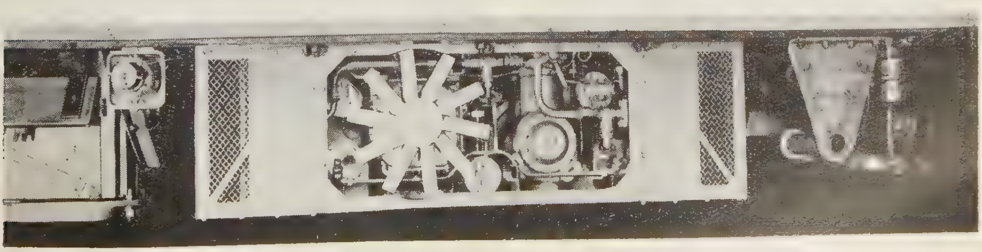


View of coach showing part of air-conditioning equipment.

Interior showing conditioned-air grilles in ceiling and re-circulating air grilles in partitions at floor level.

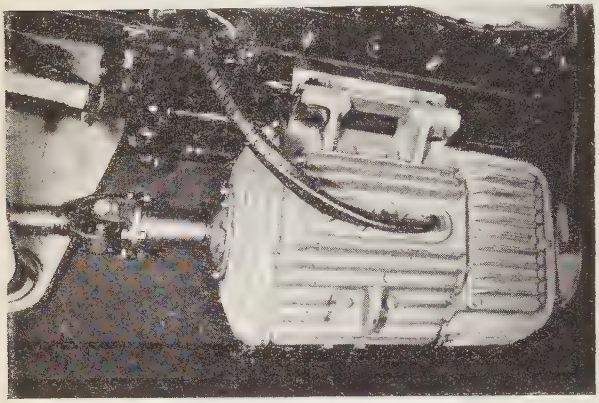


Cupboard containing air-conditioning control and switchgear.



Refrigerating unit with covers removed.

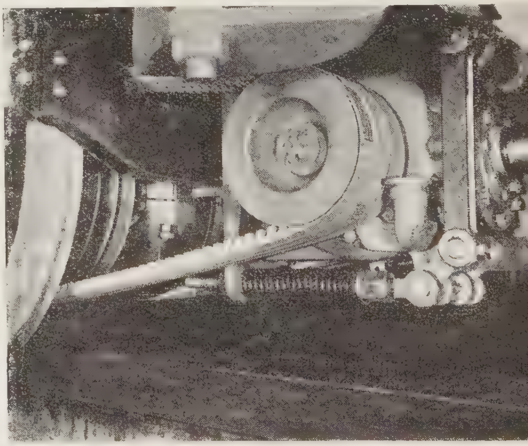
to give comfortable travelling conditions, without draughts, at all seasons of the year in Malaya. The accompanying diagram illustrates the operation of the equipment. The fresh air, drawn



Tonum generator.

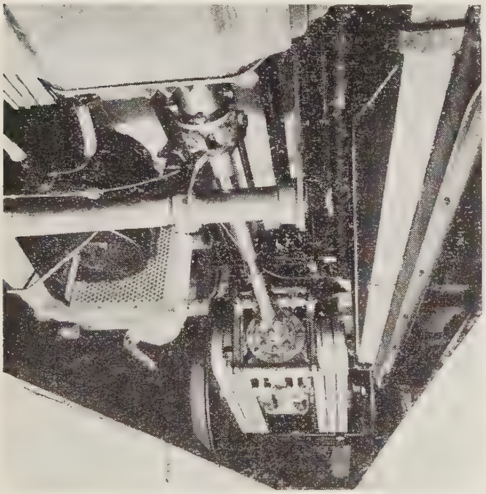
through louvres in the vestibule doors, passes up through a grille in the vestibule ceiling, and after the dust and dirt have been extracted by passing through viscous oil filters, it passes over the cooling coils of the evaporator, where a proportion of the moisture in the air condenses on the cold surface, and at the same time the temperature is reduced to the required level, according to the setting of the thermostatic control. The air is then drawn into twin centrifugal fans, forced through ducts in the double roof, and passes into the compartments through grilles which give even distribution without draughts throughout the vehicle. A portion of the air escapes to atmosphere, through small grilles in the body sides near floor level, owing to the slight pressure produced by the centrifugal fans, and the remainder returns, through grilles at the bottom of the partitions, to the vestibule end and up to the roof behind the control panel, to be recirculated.

The refrigerating unit and the evaporator operate on the normal compression system using Freon (dichlorodifluoromethane) as the refrigerant, which is non-toxic, non-irritant, and non-inflammable. The conventional refrigerating circuit is shown herewith. The Freon is circulated throughout the closed circuit by the compressor and passes from the liquid receiver through a small orifice in the expansion valve, and then on the evaporator coil. Since the evaporator coil is connected to the suction side of the compressor, there is a reduced pressure in the evaporator, and liquid Freon passing into it, vaporises into a gas. In changing its state from liquid to gas, it absorbs heat from the air passing over the coils. The gas is drawn into the compressor and compressed, which operation raises its temperature. The hot compressed gas then passes into the condenser coils where the heat extracted from the air in the car, plus the work converted into heat when the gas is compressed, is transferred to a continuous stream of atmospheric air passing over the condenser coils. The compression of the gas condenses it into a liquid which is collected in the liquid receiver, thus completing the cycle.



Generator gear drive.

The axle-driven generator supplies the power for driving the compressor and circulating fans for air-conditioning, as well as the lighting and battery charging, thus making the whole plant self-contained and not dependent on any other carriage or the locomotive. For



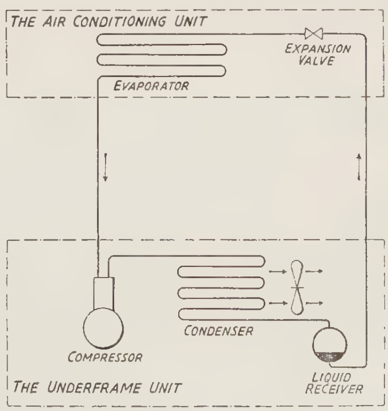
Looking upwards from inspection pit at gearbox and drive to generator.

pre-cooling, an a. c. motor is fitted which enables the plant to be run from a local a. c. supply at terminal stations. It can also be used in emergency to charge the batteries. Should the local supply be d. c., it is connected direct to the cooling motor. The sockets for plugging in local circuits are arranged to swivel so that, in the event of the train starting before disconnection, the plug is automatically pulled out.

It will be seen from the disposition of the various details of the air-conditioning equipment that there is no reduction of passenger accommodation. The air-conditioning unit, with the evaporator and the ducting, are situated in the roof, the control switchgear in a cupboard in the vestibule and all the rest of the apparatus is suitably disposed on the underframe. The total weight of the equipment is about 5 tons, inclusive of the battery.

The generator gear drive from the axle is by means of vee belts to a gearbox suspended on the bogie headstock. There are two axle pulleys, each having three vee belts, and the gearbox is carried on four suspension links attached to the bogie headstock. The links permit the correct tensioning of the belts by means of springs. The gearbox contains a pair of spiral bevel wheels running in oil. The crown wheel shaft carries the two belt pulleys and the pinion shaft carries the coupling for the propeller shaft. The generator is driven from the gearbox by means of a telescopic propeller shaft with universal joints at each end. This form of axle gear drive is very robust, quiet in operation, and flexible in application.

The Tonum type generator operates efficiently over a wide range of speed. It is totally-enclosed, dust and watertight. The generator is provided with large inspection covers in the commuta-



Refrigerating circuit.

tor end shield to permit easy access to the brush-gear. The brushes are fixed in position, and reversal of rotation is

compensated for electrically. The pre-cooling motor is of normal design for working on an a. c. supply at 400 volts, 3 phase, 50 cycles.

The storage battery, with a capacity of 520 ampere-hours at 48 volts, is composed of Stone's No-Wash cells, which are specially light in weight, and require the minimum of attention. The power for the air-conditioning equipment is taken from the generator and battery at 48 volts, but the lighting load is divided on the three-wire system so that standard 24-volt train lighting lamps and fittings can be used.

The control panel is divided into two distinct sections. The master control switches operated by the attendant for starting the equipment and for temperature control are mounted together in the upper section, and exposed to view through a glass window in the cupboard situated in the vestibule. The contactor switches, fuses, terminals, etc., are mounted in the lower section and are fully accessible when the cupboard is open. The refrigerating unit, mounted on the underframe, contains a motor-driven twin-cylinder vertical single acting compressor, the condenser, with fans for directing the air through the coils, and the liquid receiver. The pre-cooling motor is mounted alongside and is connected to the compressor by a propeller shaft with universal joints. The air-conditioning unit is situated above the vestibule ceiling and contains the evaporator, the two centrifugal fans driven by an electric motor, the expansion valve, and the viscous oil air filters.

A demonstration of one of these coaches at the Smethwick works of the Birmingham Railway Carriage & Wagon Co. Ltd. has been attended by numerous railway officers, as stated at the begining of this article.

NEW BOOKS AND PUBLICATIONS.

[536 & 621.131.2]

TONGAS (Ph.), Inspecteur divisionnaire, O. C. E. M., (Railway Equipment Central Designing Office), France. — **Une détermination graphique du volume spécifique et de la chaleur totale de la vapeur d'eau surchauffée** (*A graphical determination of the specific volume and total heat of superheated steam*). — A pamphlet (12 × 8 1/2 inches) of 11 pages, with figures. Reprinted from the *Revue Générale des Chemins de fer*, May 1936. Publisher : Dunod, 92, rue Bonaparte, Paris (VI).

When designing a triple expansion locomotive on entirely new lines the author, to facilitate the calculations, was led to draw up nomographs on the specific volume and total heat of superheated steam in terms of the pressure and temperature.

The method followed is dealt with in three chapters. In the first the author gives briefly his reasons for preferring straight-line nomographs to double entry numerical tables of the Mollier diagram or the steam entropy diagram. Chapter two gives the data on which these nomographs were built, and reproduces a number at a reduced scale. These nomographs appear to be simple, accurate and well adapted to the problem being dealt with.

The third chapter deals with the accuracy of the results obtained when the nomographs are used, and demonstrates that they can be adopted with every confidence. The author shows that in the range of pressures now in use on steam locomotives the degree of accuracy is higher than that needed in practice.

These graphs will be most useful in locomotive designing and can also be used, as they are by the O. C. E. M., to establish the heat balance sheet of locomotives tested in the testing plant.

A. C.

[**313 : 656**]

KELLERER (Dr.-Ing. Hans). — **Verkehrsstatistik** (*Statistics on transport undertakings*). — A volume (10 × 6 inches) of 264 pages with figures. — 1936, Otto Elsner Verlagsgesellschaft, Oranienstrasse, 140-142, Berlin S. 42. (Price : 18 Rm.)

The number of people using transport statistics has greatly increased during recent years, and include the managers of transport undertakings, and also institutions and investigators who are interested in the economic life of the nations. The latter finds particular expression in the operation of methods of communication, and it is well known how useful statistics can be when investigating the re-organisation of transport, a question of primary importance to-day in most civilised countries.

The object of this book is to give a picture of the many problems of which transport statistics may provide a solution, together with an indication of the methods used or to be recommended, and the conclusions to be drawn from the established data.

The author wished to make his book of practical interest. He has refrained from developing scientific theories in connection with statistics. Indeed, what he has written is really a course on statistics for professional transport opera-

tors. The staff employed by transport undertakings will see how the operations they have to carry out are expressed by statistics; the scientific enquirer, how the figures are collected and interpreted; the statistician will be convinced that transport sets statistical research a number of problems.

All kinds of transport are considered, or rather all methods of communication, as the author gives examples from the post office and telephone services as well as from the railways. They are all dealt with in every chapter, as the division of the work is based on the nature of the questions dealt with. Thus statistics on the equipment and tools used, the traffic, those analysing the use made of the stock and lines, the receipts, etc. are given in turn.

While explaining how the figures are collected, in the first place from returns used for service needs, by means of documents or other supplementary apparatus, the author several times stresses the fact that the traffic must in no way be interfered with for statistical reasons.

In a special chapter he investigates the relations between economic activity and development of means of communication and the general economic situation.

E. M.

[625. 258]

RABOURDIN (M.), Inspecteur Général du Service Central de l'exploitation des Chemins de fer de l'Est (France). — **Etude du freinage des wagons dans les gares de triage** (*The braking of goods wagons in marshalling yards*). (Lecture before the French National Organisation Committee.) — A pamphlet (10 1/2 × 8 1/4 inches) of 16 pages, with figures. — 1936, Paris, Comité National de l'Organisation française, 11bis, rue d'Aguesseau.

In this lecture the author's intention was to show the results obtained with *automatic* braking of goods wagons in shunting sidings.

First of all he explains the different braking arrangements used, and maintains the opinion that braking by means of shoes sliding on the rail offers fewer disadvantages than are commonly ascribed to it, remarking, moreover, that the braking action is proportional to the load.

After this he goes on to point out that the speed of the wagons may have to be lowered at three points : at the top of the hump, in the points zone, and in the sidings.

At the top of the hump where unduly favourable atmospheric conditions have to be compensated, shoe (slipper) brakes cannot be used. Rail brakes such as the ACEC equipment may be used.

In the area about the points and on the sidings the solution is to instal brake « elements » at carefully selected points, each element being composed of a groove followed by a recess in which the brake slipper moves, the latter being operated by a cable driven by a distant-controlled motor. By means of a pedal and a time relay the wagon can be braked proportionally to the speed at which it strikes the slipper. By suitably spacing a number of slippers their « time » can be regulated so as to obtain the desired running-off speed.

The braking can also be regulated to suit the state of occupation of the receiving siding, by track circuits acting in conjunction with relays to modify the range of times of the various braking elements. A special device is available for regulating the running-off speed, not by the position of the preceding wagon in motion, but according to the point at which it will stop.

Finally a combinator is available for altering, to suit the atmospheric conditions, the relation between the time-interval relays and the distance-run relays, so as to ensure the running wagons coming into contact at the same speed with the stationary wagons. This combinator has recently been made automatic in action.

E. M.

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[38]

BLUM (Dr.-Ing. Otto), professor at the Higher Technical School, Hanover. — **Verkehrsgeographie** (*Transport and geography*). — A volume (10 × 7 inches) of 146 pages, with 46 figures in the text. — 1936, Julius Springer, publisher, Berlin.

This books deals with the relations between geography and the usefulness, the introduction, and the development of transport. It is a field which has not been much explored by technicians, and the author regrets this, with justice it would seem, because an engineer who has to study the structure of a transport system and the location of the lines should be able to take the natural features of the countries concerned into account as well as their economic and political conditions.

The geographical elements which influence methods of communication are many and various. In particular, mention might be made of the distribution of land and sea over the face of the earth, the configuration of continents and the countries of which they are composed, the orography and hydrography of the regions served, the natural resources of the soil and subsoil, the density and distribution of the population, and the degree of civilisation.

The author shows how the sum total of characteristics of a country affect the general arrangement of the lines and decides their relative importance. He supports his thesis by examples taken from railways or other transport systems, where the effects of such geographical factors are extremely marked.

The reader will find much matter for reflection in this study, and the principles made apparent in it ought to be helpful in choosing the solution to be adopted in concrete cases.

E. M.

[621. 392]

D. v. CSILLERY and L. v. PETER. — **Die Schweissbarkeit verschiedener Stahlschienen bei Anwendung der Lichtbogenschweissung** (*Weldability of various rail steels by the electric arc process*). — Abstract from the Review *Elektroschweissung*, Nos. 3 and 4, 1936. — A pamphlet (11 3/4 × 8 inches) of, 16 pages, with tables & figures. — 1936, Braunschweig, Fried. Vieweg & Sohn, A. G.

By means of mechanical and metallographical tests, the authors investigated the possibility of applying the electric-arc welding process to various grades of rail steel.

As a result, they have come to the conclusion that if the composition of the electrodes is carefully selected and the particular operating principles suitably drawn up, this process can be applied even to special steels.

R. D.

[385. (02)]

The Railway Handbook, 1936-1937. — Published under the guidance of the Editor of *The Railway Gazette*. — One vol. (8 1/2 × 5 1/2 inches) of 96 pages with many tables. — 1935, London, The Railway Publishing Co. Ltd., 33, Tothill Street, Westminster, S. W. 1. (Price : 2 sh. 6 d.)

This is the third time this handbook has been issued in its present form and with this title. As we explained when reviewing the first edition (see January 1936 *Bulletin*) the author wanted to publish a modestly priced book, giving much of the information about the British railways contained in the *Universal Directory of Railway Officials, and Railway Year Book,* a much more important work with a much wider scope.

The statistical tables given relate to the year 1935, and show the financial results for the four great Companies, the position as regards rolling stock, staff, wages, analyses of the traffic, expenditure, etc...

One improvement is the printing of certain of the statistical tables side by side with the text referring to them. Another interesting innovation is the chronological list, extending to some dozen of pages, of the principal events in railway history, since 1801.

Though this book is limited in principle to the English and Irish railways, especially in the case of the historical facts and general statistics, the author allows exceptions to this rule by including information enabling comparisons to be made between the different countries. In the case of electric traction, the subject seems sufficiently important to warrant a brief summary of its development throughout the world. Amongst data referring to other countries mention may be made of : characteristic rolling stock gauges, the highest altitudes reached, the longest tunnels, speed records, and non-stop runs.

The present signalling practice in England is explained in one chapter. Another gives the chief modifications made in the classification of goods since 1921. A list of the many road transport undertakings in which the railways are interested financially reveals some of the preocccupation and part of the policy of the British railways.

E. M.